CTRICIANS' HANDBOOK

A REFERENCE BOOK FOR PRACTICAL ELECTRICAL WORKERS

BY
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Consulting Electrical Engineer

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AMERICAN ELECTRICIANS' HANDBOOK

PREFACE

This is a practical man's handbook.

In compiling it, the aim has been to collect such information as will enable practical electrical men—wiremen, contractors, linemen, small plant superintendents, operators and construction engineers—to select and install commercial electrical apparatus and materials intelligently for the performance of given services, and to qualify them for operating the equipment after it has been installed.

For a dozen years the compiler has maintained a personal file of loose-leaf notes on practical electrical subjects. This material constituted the nucleus around which The American Electricians' Handbook has been assembled. Additional matter has been collected from many sources. Extracts from standard books and from technical magazines have been utilized freely. Much of the text is from articles prepared by the compiler and printed in trade papers. The endeavor has been to give proper credit for all material that has appeared previously.

While this is not a so-called "theoretical" book it is theoretical to the extent that the information that it gives is based on sound physical laws, as all good engineering practice must be. However, the truths arising from the laws have been given rather than the deduction of the laws themselves. Theoretical discussion has been included only where it may be of assistance in enabling the reader to understand why he should do certain things in certain ways.

Some relatively simple subjects have been treated at considerable length, and others of a more complicated nature may, perhaps, appear to have been slighted. There are two reasons for this: *first*, space limitation considerations and *second*, the desire to cover thoroughly those things which the practical man encounters most frequently.

Illustrations and diagrams, every one of which has been especially prepared for this book, have been used very freely, because one illustration will frequently explain more than several pages of text. Many special problems are solved to indicate the proper application of the rules which are given. No attempt has been made to treat apparatus or materials involving voltages exceeding 2400.

Although this handbook has been prepared primarily for men of little schooling, it is designed to give practical information on materials, and suggestions for the selection, installation and operation of equipment, that will be of service to the technically trained engineer.

In books of this character some typographical errors are inevitable. The compiler and publishers will be glad to have notice of any that are discovered, and to have suggestions for the future enlargement and improvement of the book.

TERRELL CROFT.

UNIVERSITY CITY,
ST. LOUIS, MO.
November, 1913

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THE AMERICAN ELECTRICIANS' HANDBOOK

CONVERSION TABLES AND USEFUL FACTORS

CONVERSION FACTORS (*Standard Handbook*)

These factors were calculated with a double length slide-rule and checked with those given by Carl Hering in his "Conversion Tables."

1. Length

1 mil = 0.0254 mm. = 0.001 in.
1 mm. = 39.37 mils = 0.03937 in.
1 cm. = 0.3937 in. = 0.0328 ft.
1 in. = 25.4 mm. = 0.083 ft. = 0.0278 yd. = 2.54 cm.
1 ft. = 304.8 mm. = 12 in. = 0.333 yd. = 0.305 m.
1 yd. = 91.44 cm. = 36 in. = 3 ft. = 0.914 m.
1 m. = 39.37 in. = 3.28 ft. = 1.094 yd.
1 km. = 3,281 ft. = 1,094 yd. = 0.6213 miles.
1 mile = 5,280 ft. = 1,760 yd. = 1,609 m. = 1.609 km.

2. Surface

1 cir. mil = 0.7854 sq. mil = 0.0005067 sq. mm. = 0.0000007854 sq. in.
1 sq. mil = 1.273 cir. mil = 0.000645 sq. mm. = 0.000001 sq. in.
1 sq. mm. = 1,973 cir. mil = 1,550 sq. mil = 0.00155 sq. in.
1 sq. cm. = 197,300 cir. mil = 0.155 sq. in. = 0.00108 sq. ft.
1 sq. in. = 1,273,240 cir. mil = 6.451 sq. cm. = 0.0069 sq. ft.
1 sq. ft. = 929.03 sq. cm. = 144 sq. in. = 0.1111 sq. yd. = 0.0929 sq. m.
1 sq. yd. = 1,296 sq. in. = 9 sq. ft. = 0.00836 are = 0.000207 acre.
1 sq. m. = 1,550 sq. in. = 10.7 sq. ft. = 1.195 sq. yd. = 0.000247 acre.
1 acre = 43,560 sq. ft. = 4,840 sq. yd. = 4,047 sq. m. = 0.4047 hectare = 0.004047 sq. km. = 0.001562 sq. mile.
1 sq. mile = 27,880,000 sq. ft. = 3,098,000 sq. yd. = 2,590,000 sq. m. = 640 acres = 2.59 sq. km.

3. Volume

1 cir. mil-ft. = 0.0000094248 cu. in.
1 cu. cm. = .061 cu. in. = 0.0021 pt. (liq.) = 0.0018 pt. (dry).
1 cu. in. = 16.39 cu. cm. = 0.0346 pt. (liq.) = 0.0298 pt. (dry). = 0.0173 qt. (liq.) = 0.0148 qt. (dry) = 0.0164 l. or cu. dm. = 0.0036 gal. = 0.0005787 cu. ft.
1 pt. (liq.) = 473.18 cu. cm. = 28.87 cu. in.
1 pt. (dry) = 550.6 cu. cm. = 33.60 cu. in.

1 qt. (liq.) = 946.36 cu. cm. = 57.75 cu. in. = 8 gills (liq.) = 2 pt. (liq.) = 0.94636 l. or cu. dm. = 0.25 gal.

1 l. = 1,000 cu. cm. = 61.023 cu. in. = 2.1133 pt. (liq.) = 1.8162 pt. (dry) = 0.908 qt. (dry) = 0.2642 gal. (liq). = 0.03531 cu. ft.

1 qt. (dry) = 1,101 cu. cm. = 67.20 cu. in. = 2 pt. (dry) = 0.03889 cu. ft.

1 gal. = 3,785 cu. cm. = 231 cu. in. = 32 gills = 8 pt. = 4 qt. (liq.) = 3.785 l = 0.1337 cu. ft. = 0.004951 cu. yd.

1 cu. ft. = 28,317 cu. cm. = 1,728 cu. in. = 59.84 pt. (liq.) = 51.43 pt. (dry) = 29.92 qt. (liq). = 28.32 l. = 25.71 qt. (dry) = 7.48 gal. = 0.03704 cu. yd. = 0.02832 cu. m. or stere.

1 cu. yd. = 46,656 cu. in. = 27 cu. ft. = 0.7646 cu. m. or stere.

1 cu. m. = 61,023 cu. in. = 1,000 l = 35.31 cu. ft. = 1.308 cu. yd.

4. Weight

1 mg. = 0.01543 gr. = 0.001 g.

1 gr. = 64.80 mg. = 0.002286 oz. (av.)

1 g. = 15.43 gr. = 0.03527 oz. (av.) = 0.002205 lb. (av.)

1 oz. (av.) = 437.5 gr. = 28.35 g. = 16 drams (av.) = 0.0625 lb. (av.)

1 lb. (av.) = 7,000 gr. = 453.6 g. = 256 drams = 16 oz. = 0.4536 kg.

1 kg. = 15,432 gr. = 35.27 oz. = 2.205 lb.

1 ton (short) = 2,000 lb. (av.) = 907.2 kg. = 0.9072 ton (metric) 0.8928 ton (long).

1 ton (long) = 2,240 lb. = 1.12 ton (short) = 1.016 ton (metric).

5. Energy

Torque units should be distinguished from energy units: Thus, foot-pound and kilogram-meter for energy, and pound-foot and meter-kilogram for torque. (See 1–88 for further information on torque.)

1 ft-lb.* = 13,560,000 ergs = 1.356 joules = 0.3239 g-cal. = 0.1383 kg-m. = 0.001285 B.t.u. = 0.0003766 watt-hr. = 0.0000005051 h.p.-hr.

1 kg-m. = 98,060,000 ergs = 9.806 joules = 7.233 ft-lb. = 2.34 g-cal. = 0.009296 B.t.u. = 0.002724 watt-hr. = 0.000003704 h.p.-hr. (metric).

1 B.t.u. = 1,055 joules = 778.1 ft-lb. = 252 g-cal. = 107.6 kg-m. = 0.5555 lb-centigrade heat unit = 0.2930 watt-hr. = 0.252 kg-cal. = 0.0003984 h.p.-hr. (metric) = 0.0003930 h.p.-hr.

1 watt-hr. = 3,600 joules = 2655.4 ft-lb. = 860 g-cal. = 367.1 kg-m. = 3.413 B.t.u. = 0.001341 h.p.-hr.

1 h.p.-hr. = 2,684,000 joules = 1,980,000 ft-lb. = 273,700 kg-cm. = 745.6 watt-hr.

1 kw-hr. = 2,655,000 ft-lb. = 367,100 kg-m. = 1.36 h.p.-hr. (metric) = 1.34 h.p.-hr.

6. Power

1 g-cm. per sec. = 0.00009806 watt.

1 ft-lb. per min. = 0.02260 watt = 0.00003072 h.p. (metric) = 0.00000303 h.p.

1 watt = 44.26 ft-lb. per min. = 6.119 kg-m. per min. = 0.001 kilowatt.

* The hyphen (-) as used here means "multiplied by."

1 **h.p.** = 33,000 ft-lb. per min. = 745.6 watts = 550 ft-lb. per sec. = 76.04 kg-m. per sec. = 1.01387 h.p. (metric).

1 **kw.** = 44256.7 ft-lb. per min. = 101.979 kg-m. per sec. = 1.3597 h.p. metric) = 1.341 h.p.

7. Resistivity

1 **ohm per cir. mil-ft.** = 0.7854 ohm per sq. mil-ft. = 0.001662 ohm per sq. mm-m. = 0.0000001657 ohm per cm.^{3} = 0.00000006524 ohm per in.^{3}

1 **ohm per sq. mil-ft.** = 1.273 ohms per cir. mil-ft. = 0.002117 ohm per sq. mm-m. = 0.0000002116 ohm per cm.^{3} = 0.00000008335 ohm per in.^{3}

1 **ohm per in.^{3}** = 15,280,000 ohms per cir. mil-ft. = 12,000,000 ohms per sq. mil-ft. = 25,400 ohms per sq. mm-m. = 2.54 ohms per cm.^{3}

8. Current Density

1 **amp. per sq. in.** = 0.7854 amp. per cir. in. = 0.1550 amp. per sq. cm. = 1,273,000 cir. mils per amp. = 0.000001 amp. per sq. mil.

1 **amp. per sq. cm.** = 6.45 amp. pei sq. in. = 197 000 cir. mils per amp.

1,000 **cir. mils per amp.** = 1,273 amp. per sq. in.

1,000 **sq. mils per amp.** = 1,000 amp. per sq. in.

9. Table Showing Fractions of Inch Reduced to Decimal Equivalents

64ths	32ds	16ths	8ths	4ths	Halves	Decimal equivalents	64ths	32ds	16ths	8ths	4ths	Halves	Decimal equivalents
1/64						0.015625	33/64						0.515625
	1/32					0.031250		17/32					0.531250
3/64						0.046875	35/64						0.546875
		1/16				0.062500			9/16				0.562500
5/64						0.078125	37/64						0.578125
	3/32					0.093750		19/32					0.593750
7/64						0.109375	39/64						0.609375
			1/8			0.125000				5/8			0.625000
9/64						0.140625	41/64						0.640625
	5/32					0.156250		21/32					0.656250
11/64						0.171875	43/64						0.671875
		3/16				0.187500			11/16				0.687500
13/64						0.203125	45/64						0.703125
	7/32					0.218750		23/32					0.718750
15/64						0.234375	47/64						0.734375
				1/4		0.250000					3/4		0.750000
17/64						0.265625	49/64						0.765625
	9/32					0.281250		25/32					0.781250
19/64						0.296875	51/64						0.796875
		5/16				0.312500			13/16				0.812500
21/64						0.328125	53/64						0.828125
	11/32					0.343750		27/32					0.843750
23/64						0.359375	55/64						0.859375
			3/8			0.375000				7/8			0.875000
25/64						0.390625	57/64						0.890625
	13/32					0.406250		29/32					0.906250
27/64						0.421875	59/64						0.921875
		7/16				0.437500			15/16				0.937500
29/64						0.453125	61/64						0.953125
	15/32					0.468750		31/32					0.968750
31/64						0.484375	63/64						0.984375
					1/2	0.500000							

10. Trigonometric Functions

Angle ϕ or *lag angle*	Sin or *induction factor*	Cos or *power factor*	Tan	Angle ϕ or *lag angle*	Sin or *induction factor*	Cos or *power factor*	Tan
0	.000	1.000	.000	....	....	....	....
1	.017	.999	.017	46	.719	.695	1.04
2	.035	.999	.035	47	.731	.682	1.07
3	.052	.999	.052	48	.743	.669	1.11
4	.070	.998	.070	49	.755	.656	1.15
5	.087	.996	.087	50	.766	.643	1.19
6	.105	.995	.105	51	.777	.629	1.23
7	.122	.993	.123	52	.788	.616	1.28
8	.139	.990	.141	53	.799	.602	1.33
9	.156	.988	.158	54	.809	.588	1.38
10	.174	.985	.176	55	.819	.574	1.43
11	.191	.982	.194	56	.829	.559	1.48
12	.208	.978	.213	57	.839	.545	1.54
13	.225	.974	.231	58	.848	.530	1.60
14	.242	.970	.249	59	.857	.515	1.66
15	.259	.966	.268	60	.866	.500	1.73
16	.276	.961	.287	61	.875	.485	1.80
17	.292	.956	.306	62	.833	.469	1.88
18	.309	.951	.325	63	.891	.454	1.96
19	.326	.946	.344	64	.898	.438	2.05
20	.342	.940	.364	65	.906	.423	2.14
21	.358	.934	.384	66	.914	.407	2.25
22	.375	.927	.404	67	.921	.391	2.36
23	.391	.921	.424	68	.927	.375	2.48
24	.407	.914	.445	69	.934	.358	2.61
25	.423	.906	.466	70	.940	.342	2.75
26	.438	.898	.488	71	.946	.326	2.90
27	.454	.891	.510	72	.951	.309	3.08
28	.469	.883	.532	73	.956	.292	3.27
29	.485	.875	.554	74	.961	.276	3.49
30	.500	.866	.577	75	.966	.259	3.73
31	.515	.857	.601	76	.970	.242	4.01
32	.530	.848	.625	77	.974	.225	4.33
33	.545	.839	.649	78	.978	.208	4.70
34	.559	.829	.675	79	.982	.191	5.14
35	.574	.819	.700	80	.985	.174	5.67
36	.588	.809	.727	81	.988	.156	6.31
37	.602	.799	.754	82	.990	.139	7.12
38	.616	.788	.781	83	.993	.122	8.14
39	.629	.777	.810	84	.995	.105	9.51
40	.643	.766	.839	85	.996	.087	11.43
41	.656	.755	.869	86	.998	.070	14.30
42	.669	.743	.900	87	.999	.052	19.08
43	.682	.731	.933	88	.999	.035	28.64
44	.695	.719	.966	89	.999	.017	57.28
45	.707	.707	1.000	90	1.000	.000	Infinity

PRINCIPLES OF ELECTRICITY AND MAGNETISM—UNITS

11. **It is not known just what electricity is** and from a practical standpoint it does not appear to make much difference what it is. We know a great deal about certain things that it will do, can measure its effects and are familiar with many ways of utilizing it.

It has been established that electricity, whatever it may be, is not energy. (Energy, in the technical sense, is stored work or capacity for doing work.) Electricity and magnetism may be thought of as weightless mediums which carry energy

just as do water (Fig. 1) or air or any other form of matter and the laws which govern the flow of electricity, in closed circuits, are, in general, similar to those governing the flow in closed water and air circuits. Electricity is not energy any more than the water flowing under pressure in the pipe line of Fig. 1 is energy. The water flowing in the pipe (Fig. 1) is a means of transmitting energy and so is the electricity flowing along the conductor of Fig. 2 a means of transmitting energy.

In Fig. 1, the energy developed by the steam engine is transmitted to the rotary pump by means of the belt. The rotary pump forces the water through the pipe to turn a water-motor

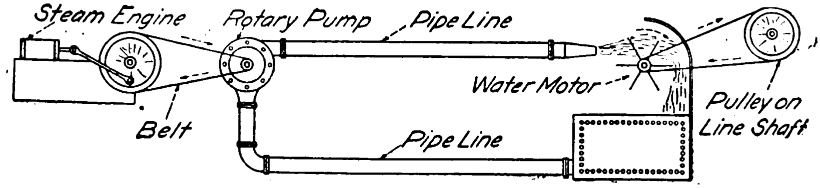


FIG. 1.—Transmitting energy with water.

which, in turn, through a belt, drives a line shaft. Thus, a belt, a rotary pump, a water-motor and another belt have all been mediums in the transmission of energy from the engine to the line shaft. In Fig. 2 an electric generator or dynamo is substituted for the rotary pump, conductors for the pipe line, and an electric motor for the water-motor. In Fig. 2 electricity instead of water is the medium by means of which energy is transmitted over the long distance, otherwise the two transmission systems are somewhat similar. In either Fig. 1 or Fig. 2 a long belt might be arranged between the engine and the line-shaft pulley and it would transmit energy just as do water or electricity, though possibly not as efficiently. (Obviously, belt transmission over any great

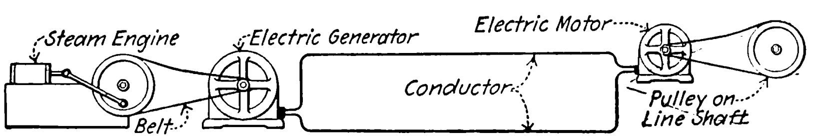


FIG. 2.—Transmitting energy with electricity.

distance is not feasible.) These illustrations have been given to show that **electricity is merely a medium for the transmission of energy** and that it is not energy.

12. Current. Amperes.—The practical unit of electric current is the ampere. If a pressure of 1 volt is impressed on a closed circuit having a resistance of 1 ohm, 1 ampere will flow. The flow of water in a pipe is measured by the quantity of water that flows through in a second as 1 gal. per sec., 8 gal. per sec., etc. Similarly the flow of electricity in a circuit is measured by the amount of electricity that flows along it in a second, as "1 coulomb per second." The **coulomb** is the name given to a certain quantity of electricity just as the gallon is the name given a certain quantity of water. The name given to a rate of flow of *a coulomb per second* is

the ampere. If 2 coulombs per second flow the current is 2 amperes; if 20 coulombs per second flow the current is 20 amperes. It is the amount of electricity that flows in a second rather than the total amount that flows that is of importance. Hence the unit of amount, the coulomb, is practically never used by the electrician.

13. **The volt** is the practical unit of electromotive force or electrical pressure. The volt is that difference in pressure that will force a current of 1 ampere through a resistance of 1 ohm. "Electromotive force" is abbreviated e.m.f.

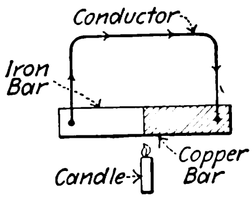


FIG. 3.—E.m.f. generated by heat.

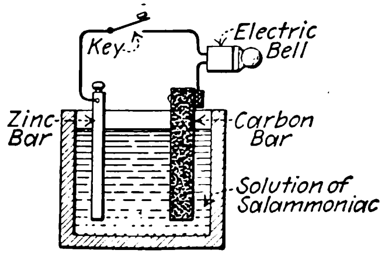


FIG. 4.—E.m.f. generated by chemical action.

14. **Electromotive forces may be generated in three different ways,** viz.: (1) *By contact of unlike substances either by the application of heat or by chemical action.* Heat applied to the junction of two dissimilar metals (Fig. 3) will generate an e.m.f., but it will be relatively small. This method is not commercial. If a piece of carbon and a piece of zinc (Fig. 4) are immersed in a solution of sal-ammoniac a battery results that will generate an e.m.f. If the key is closed an electric current will flow and the bell will ring. (2) *By magnetic flux.* If the conductor, Fig. 5, be moved

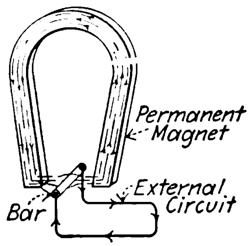


FIG. 5.—E.m.f. generated by magnetic flux.

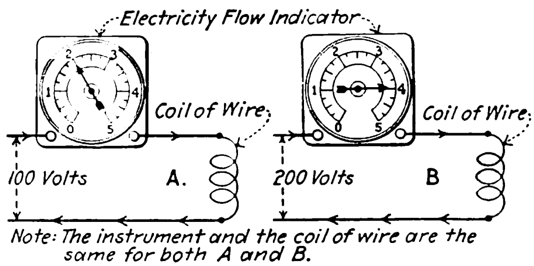


FIG. 6.—Illustrating the effect of increasing electric pressure.

up and down so as to cut the lines of force between the poles of the magnet an e.m.f. will be generated. This illustrates the principle of the dynamo and the principle of the cheapest way to generate an e.m.f. if a large quantity of electricity is required. (3) *By dielectric flux.* Illustrations are the e.m.f. generated by rubbing a comb through the hair, and that generated by the slipping of a belt on a pulley. The electricity produced is called static electricity. This method is of little commercial importance.

15. **Hydraulic Analogy of e.m.f.**—The number of gallons per second (Timbie's Elements of Electricity) of water flowing

through a pipe depends, to a large extent on the hydraulic pressure on the pipe. (Water pressure is measured in pounds per square inch.) Similarly, electric pressure or e.m.f., measured in volts, causes electricity to flow. A volt means somewhat the same thing in speaking of a flow of electricity as a pound pressure does in speaking of a flow of water. A higher hydraulic pressure is required to force a given amount of water through a small pipe than through a large one. Similarly a higher voltage is required to force a given

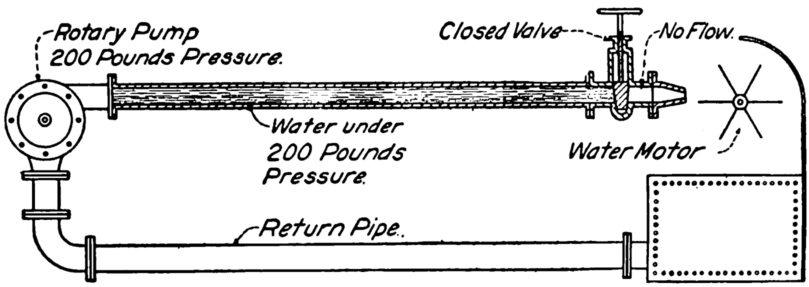


FIG. 7.—Water flow blocked by a closed valve.

amount of electricity through a small wire than through a large one. If the voltage impressed on a circuit is increased the current will be correspondingly increased. See Fig. 6.

16. **The distinction between amperes and volts** should (Timbie) be clearly understood. The amperes represent the rate of electricity flow (see Par. 12) through a circuit while the volts represent the pressure causing the flow. In the case of both electricity and water there may be great pressure and yet no current. If the path of the water is blocked by a closed valve (Fig. 7) there

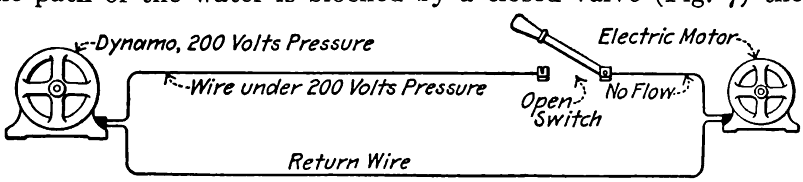


FIG. 8.—Electricity flow blocked by an open switch.

will be no current (flow of water)yet there may be high pressure. If the path of electricity is blocked by an open switch, Fig. 8, there will be no current of electricity, though the pressure (voltage) might be high. Furthermore, it is evident that, with a given hydraulic pressure, more water will flow through a large pipe than through a small one. Similarly with a given voltage, more electricity will flow through a large wire than through a small one.

17. **Resistance** is the physical property of a material by virtue of which it opposes the flow of an electric current. **The ohm** is the practical unit of resistance. If a pressure of 1 volt is impressed on a circuit and 1 ampere flows, that circuit has a resistance of 1 ohm. A column of mercury 106.3 cm. long, having a cross-sectional area of 1 square millimeter will have a resistance of 1 ohm. A piece of No. 10 copper wire 1000 ft. long has a resistance of almost exactly 1 ohm.

18. A resistor is an object having resistance; specifically, a resistor is a conductor inserted in a circuit to introduce resistance. **A rheostat** is a resistor so arranged that its effective resistance can be varied.

19. What Determines Resistance.—The amount of resistance offered to the flow of water through a pipe or to the flow of electricity through a conductor is determined by somewhat analogous properties of the pipe and of the conductor respectively, as follows:

20. Properties Determining Flow

Of water through a pipe	Of electricity through a wire
1. Diameter of pipe.	1. Diameter of wire.
2. Length of pipe.	2. Length of wire.
3. Material of pipe and its internal smoothness.	3. Material of wire and its temperature.

With both electricity and water flow (assuming a constant pressure) the longer the wire or pipe the less the flow; the smaller the diameter of wire or pipe, the less the flow and vice versa.

21. The resistances of different materials vary greatly. Some, such as the metals, conduct electricity very readily, hence are called conductors. Others such as wood or slate are, at least when moist, partial conductors. Still others, such as glass, porcelain and paraffin, are called insulators because they are practically non-conducting. No material is a perfect conductor and no material is a perfect insulator.

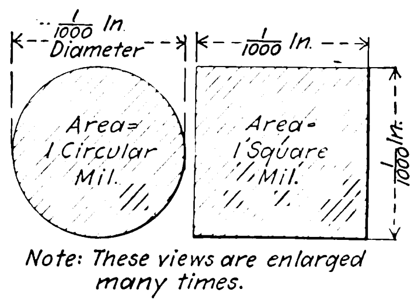


FIG. 9.—Circular mil and square mil.

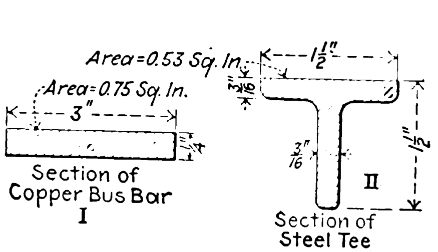


FIG. 10.—Conductor sections.

22. A circular mil is the area of a circle $\frac{1}{1000}$ in. in diameter. A mil is $\frac{1}{1000}$ of an inch. See Fig. 9. The areas of electric conductors are usually measured in cir. mils. Since the area of any figure varies as the square of its similar dimensions, the area of any circle can be expressed in cir. mils by squaring its diameter expressed in thousandths. Thus, since $\frac{3}{8} = \frac{375}{1000} = 0.375$, the area of a circle $\frac{3}{8}$ in. in diameter would be $375 \times 375 = 140{,}625$ cir. mils. The area of a circle 0.005 in. diameter would be $5 \times 5 = 25$ cir. mils.

23. A square mil is the area of a square having sides $\frac{1}{1000}$ in. long. See Fig. 9. Areas of rectangular conductors are sometimes measured in square mils. Areas in sq. mils are obtained by multiplying together the length and breadth of the rectangle expressed in thousandths of an inch. Thus, the area of a rectangle $\frac{1}{2}$ in. wide and 2 in. long would be $500 \times 2000 = 1{,}000{,}000$ sq. mils. In actual area, a circular mil is about $\frac{8}{10}$ as great as a square mil.

24. To reduce square mils or square inches to circular mils or the reverse use the following formulas:

$$\text{Sq. mils} = \text{cir. mils} \times 0.7854$$

$$\text{Cir. mils} = \frac{\text{sq. mils}}{0.7854}$$

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854}$$

$$\text{Sq. in.} = \text{cir. mils} \times 0.0000007854$$

Example.—The sectional area of the bus bar, in Fig. 10, I, is in cir. mils:

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854} = \frac{3 \times \frac{1}{4}}{0.0000007854} = \frac{0.75}{0.0000007854} = 955{,}000 \text{ cir. mils.}$$

Example.—The sectional area of the steel tee, shown in Fig. 10, II, in cir. mils is:

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854} = \frac{0.53}{0.0000007854} = 674{,}800 \text{ cir. mils.}$$

25. The circular mil-foot (cir. mil-ft.) is the unit conductor. A wire having a sectional area of one circular mil and a length of one foot is a cir. mil-ft. of conductor. The resistance of a cir. mil-ft. of a metal is sometimes called its **specific resistance** or **its resistivity.** The resistance of a cir. mil-ft. of copper under different conditions is given in Fig. 11. Resistances for other metals and alloys are given in Table **28.**

26. To obtain the resistance of a conductor of any common metal or alloy use the value given for the resistance of a cir. mil-ft. of the material in Table **28** in the following formula:

$$R = \frac{p \times l}{\text{cir. mils}} \quad \text{or} \quad \frac{p \times l}{d^2}$$

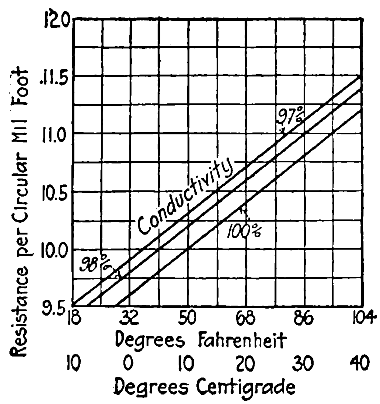


FIG. 11.—Curves showing resistance per circular mil-foot of pure copper at various temperatures and conductivities.

Wherein R = resistance of the conductor in ohms, p = resistance of a cir. mil-ft. of the material composing the conductor, from Table **28,** l = length of conductor in feet, d = diameter in mils and d^2 = diameter in mils squared or, what is the same thing, the area of the conductor in circular mils. The other forms of the formula are:

$$p = \frac{d^2 \times R}{l} \qquad l = \frac{d^2 \times R}{p} \qquad d = \sqrt{\frac{p \times l}{R}}$$

Example.—Taking from the Table 29 the resistance of a cir. mil-ft. of copper at 23° C. (75° F.) as 10.5 ohms, what is the resistance of 500 ft. of copper wire, 0.021 in. diameter?

Solution.—Substituting in the formula:

$$R = \frac{pl}{d^2} = \frac{10.5 \times 500}{21 \times 21} = \frac{5250}{441} = 11.9 \text{ ohms.}$$

27. The resistances of conductors that are not circular in section can be computed by first getting their areas in sq. in. and then reducing this sq. in. value to cir. mils as indicated above. Then proceed with the formula in the preceding paragraph.

28. Approximate Specific Resistances and Temperature Coefficients of Metals and Alloys

(International Textbook Company—Electrical Engineer's Handbook)

Metal	ρ Resistance of 1 cir. mil-foot in ohms		a Average temperature coefficient per degree C. between 0° and 100° C.	a Average temperature coefficient per degree F. between 32° and 212° F.	Percentage conductivity	Relative resistance
	0° C. or 32° F.	23.8° C. or 75° F.				
Silver, pure annealed	8.831	9.674	0.004000	0.002220	108.60	0.925
Copper, pure annealed	9.390	10.351	0.004280	0.002380	102.10	0.980
Copper, annealed	9.590	10.505	0.004020	0.002230	100.00	1.000
Copper, hard-drawn	9.810	10.745	0.004020	0.002230	97.80	1.022
Gold (99.9% pure)	13.216	14.404	0.003770	0.002090	72.55	1.378
Aluminum (99.5% pure)	15.219	16.758	0.004230	0.002350	63.00	1.587
(Commercial—97.5% pure)	16.031	17.699	0.004350	0.002420	59.80	1.672
Zinc (very pure)	34.595	37.957	0.004060	0.002260	27.72	3.608
Iron, (approx. pure)	54.529	62.643	0.006250	0.003470	17.50	5.714
Iron "E. B. B." iron wire	58.702	65.190	0.004630	0.002570	16.20	6.173
Platinum (pure)	65.670	71.418	0.003669	0.002038	14.60	6.845
Iron, "B. B." iron wire	68.680	76.270	0.004630	0.002570	13.50	7.407
Nickel	74.128	85.138	0.006220	0.003460	12.94	7.726
Tin (pure)	78.489	86.748	0.004400	0.002450	12.22	8.184
Steel (wire)	81.179	90.150	0.004630	0.002570	11.60	8.621
Substance						
Brass	43.310	......	......	......	22.15	4.515
Phosphor-bronze	51.005	......	0.000640	0.000356	18.80	5.319
Aluminum bronze	73.989	......	0.001000	0.000556	12.96	7.714
German silver *Cu* 50, *Zn* 35, *Ni* 15	127.800	......	0.000400	0.000220	7.50	17.300
Platinoid, *Cu* 59, *Zn* 25.5, *Ni* 14, *W* (tungsten) 55	251.030	......	0.000310	0.000172	3.82	26.180
Manganin *Cu* 84, *Ni* 4, *Mn* 12	280.790	......	0.000000	......	3.41	29.330
Constantan, *Cu* 58, *Ni* 41, *Mn* 1	{300.77 / 312.80}	......	±0.000010	0.000005	{3.19 / 3.07}	{31.35 / 32.57}
Gray cast iron	684.000	......	......	......	......	......

29. Change of Resistance with Change of Temperature.—The resistance of all pure metals increases as they become hot. The resistance of certain alloys is not affected by the temperature. In wiring for light and power, changes in resistance due to changes in temperature are so slight that they may be wholly disregarded. Sometimes, with electrical machinery, changes in resistance due to changes in temperature may be of importance, in that speeds, voltages or currents may be appreciably affected thereby. The proportion that resistance increases per degree rise in temperature is called the **temperature coefficient of resistance.** See Table 28 for values. For all pure metals, the coefficient is practically the same and is 0.004 for temperatures in degrees Centigrade and 0.0023 for temperatures in degrees Fahrenheit.

30. To find the resistance of a conductor at any ordinary temperature, use this formula:

$$R_h = R_c + a \times R_c\ (T_h - T_c) \text{ or } T_h - T_c = \frac{R_h - R_c}{a \times R_c}$$

Wherein R_h = resistance in ohms hot, R_c = resistance in ohms cold, T_h = temperature of conductor hot, in degrees, T_c = temperature of conductor cold in degrees and a = the temperature coefficient of the material of the conductor from Table 28. (This is an approximate method, but it is sufficiently accurate for all ordinary work.)

Example.—The resistance of a cir. mil-ft. of annealed copper is 9.59 ohms at 32° F. What will its resistance be at 75° F.?

Solution.—From Table 28 the coefficient is 0.00223. Substitute in the formula:

$$\begin{aligned} R_h = R_c + a \times R_c(T_h - T_c) &= 9.59 + 0.00223 \times 9.59(75 - 32) \\ &= 9.59 + 0.00223 \times 9.59 \times 43 \\ &= 9.59 + 0.92 \\ &= 10.51 \text{ ohms, at } 75° \text{ F.} \end{aligned}$$

31. The Temperature Rise in a Conductor can be Determined with the above Formula by Measuring Hot and Cold Resistance.—The expression "$T_h - T_c$" is the difference between the hot and cold temperature and is therefore the temperature rise or fall.

Example.—The resistance of a set of copper coils measured 20 ohms at a room temperature of 20° C. After carrying current for some time the resistance measured 20.78 ohms. What was the temperature rise in the coil?

Solution.—The temp. coef. of copper per degree C. is, from Table 28, 0.004. Substitute in the formula:

$$T_h - T_c = \frac{R_h - R_c}{aR_c} = \frac{20.78 - 20.0}{0.004 \times 20} = \frac{0.78}{0.08} = 9.75° \text{ C.}$$

Therefore the average temperature rise in the coil was 9¾° C.

32. Contact resistance is the resistance at the point of contact of two conductors. Heat is always developed at such a point when current flows. The greater the clamping pressure between the conductors in contact and the greater the area of contact, the less the contact resistance will be. The nature of the surfaces in contact must also be considered. Smooth surfaces have less contact resistance than do rough surfaces. Contacts should always be so designed that, for a given current, the area of contact will be large enough that the contact resistance will not be so great as to cause excessive heating. Table 33 indicates safe values.

33. Safe Current Densities for Electrical Contacts and for Cross Sections

Kind of contact	Material	Current density: Amperes per square inch	Current density: Square mils per ampere
Sliding contact (brushes)	Copper brush	150 to 175	5700 to 6700
	Brass gauze brush	100 to 125	8000 to 10000
	Carbon brush	30 to 40	25000 to 33300
Spring contact (switch blades)	Copper on copper	60 to 80	12500 to 16700
	Composition on copper	50 to 60	16700 to 20000
	Brass on brass	40 to 50	20000 to 25000
Screwed contact	Copper to copper	150 to 200	5000 to 6700
	Composition to copper	125 to 150	6700 to 8000
	Composition to composition	100 to 125	8000 to 10000
Clamped contact	Copper to copper	100 to 125	8000 to 10000
	Composition to copper	75 to 100	10000 to 13000
	Composition to composition	70 to 90	11000 to 14000
Fitted contact (taper plugs)	Copper to copper	125 to 175	5700 to 8000
	Composition to copper	100 to 125	8000 to 10000
	Composition to composition	75 to 100	10000 to 13000
Fitted and screwed contact	Copper to copper	200 to 250	4000 to 5000
	Composition to copper	175 to 200	5000 to 5700
	Composition to composition	150 to 175	5700 to 6700
Cross section	Copper wire	1200 to 2000	500 to 800
	Copper wire cable	1000 to 1600	600 to 1000
	Copper rod	800 to 1200	800 to 1200
	Composition casting	500 to 700	1400 to 2000
	Brass casting	300 to 400	2500 to 3300
	Brass rod	575 to 750	1300 to 1700

34. Ohm's Law.—There is a simple relation between the electromotive force (volts), the current (amperes) and the resistance (ohms) in an electric circuit. This relation is expressed by Ohm's law, viz: *The electric current in a conductor equals the electromotive force divided by the resistance.* Expressing this law in symbols:

$$I = \frac{E}{R} \qquad \text{or} \qquad R = \frac{E}{I} \qquad \text{or} \qquad E = I \times R$$

Wherein, I = the current in amperes, E = the electromotive force in volts and R = the resistance in ohms.

In the above form, Ohm's law applies only to direct-current circuits or non-inductive alternating-current circuits. Where inductive alternating-current circuits are involved it must be modified before application. See index.

35. In applying Ohm's law many errors are made. It can be applied to an entire circuit or to only a portion of a circuit. When applied to an entire circuit (Timbie): *The current (amperes) in the entire circuit equals the voltage across the entire circuit divided by the resistance (ohms) of the entire circuit.* Note that the word *entire* applies to current, voltage and resistance alike. When applied to but part of a circuit (Timbie): *The current in a certain part of a*

circuit equals the voltage across that same part divided by the resistance of that part.

36. Examples of the Application of Ohm's law.

Example.—What will be the current in the circuit of Fig. 12?

Solution.—An entire circuit is shown. It is composed of a dynamo, line wires and a resistance coil. The e.m.f. developed by the dynamo (do not confuse this with the e.m.f. impressed by the dynamo on the line), is 120 volts. The resistance of the entire circuit is the sum of the resistances of dynamo, line wires and resistance coil. Substituting in the formula:

$$I = \frac{E}{R} = \frac{120}{1+1+9+1} = \frac{120}{12} = 10 \text{ amp.}$$

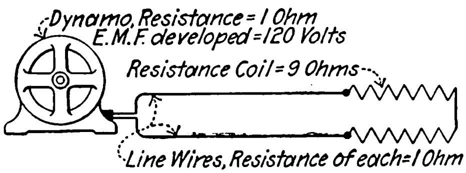


FIG. 12.—An entire dynamo circuit.

Example.—What current will flow in the circuit of Fig. 13?

Solution.—This again is an entire circuit. Substituting in the formula:

$$I = \frac{E}{R} = \frac{1}{0.5+0.5+2+0.5} = \frac{1}{3.5} = 0.28 \text{ amp.}$$

Note that the internal resistance of the battery must be considered.

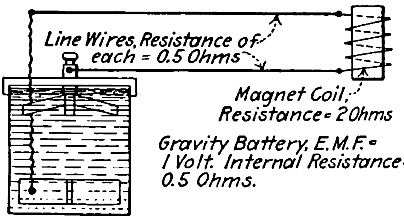


FIG. 13.—An entire battery circuit.

Example.—With 10 amp. flowing, what will be the voltage or drop across each of the line wires in Fig. 14?

Solution.—Each has a resistance of 0.1 ohm, hence

$$E = I \times R = 10 \times 0.1 = 1 \text{ volt.}$$

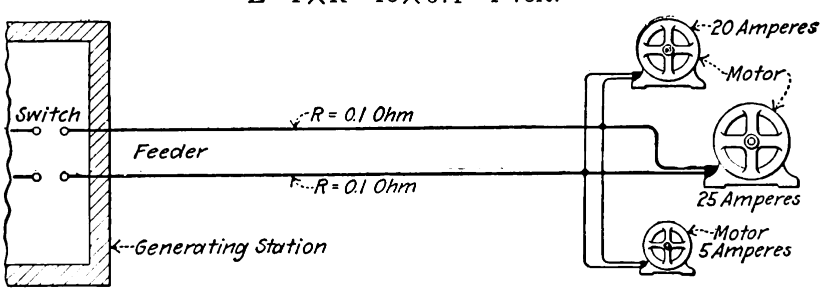


FIG. 14.—Feeder to motors.

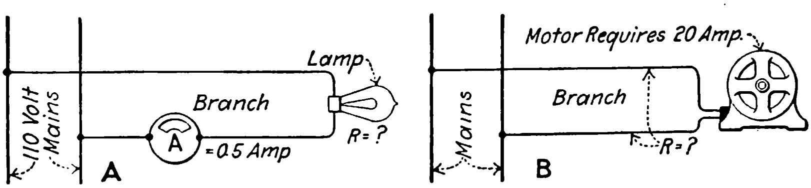


FIG. 15.—Portions of circuits.

Example.—What is the resistance of the incandescent lamp of Fig. 15? It is tapped to a 110-volt circuit and the ammeter reads 0.5 amperes. The branch wires are so short that their resistance can be neglected.

Solution.—Substitute in the formula:

$$R = \frac{E}{I} = \frac{110}{0.5} = 220 \text{ ohms.}$$

Example.—The motor of Fig. 15*B* takes 20 amperes and the drop in voltage in the branch wires should not exceed 5 volts. What is the greatest resistance that can be permitted in the branch conductors?

Solution.—Substitute in the formula:

$$R = \frac{E}{I} = \frac{5}{20} = 0.25 \text{ ohms.}$$

This (0.25 ohm) is the resistance of both wires. Each would have a resistance of 0.125 ohm.

Example.—The arc lamp Fig. 16 takes 5 amperes. The resistance of each branch wire is 0.1 ohm. What will be the drop in volts in each branch wire?

Solution.—Substitute in the formula:

$$E = R \times I = 0.1 \times 5 = 0.5 \text{ volts.}$$

In both branch wires or in the branch circuit the volts lost would be $2 \times 0.5 = 1$ volt.

Example.—Three motors (Fig. 14) taking respectively 20 amperes, 25 amperes and 5 amperes (these values were stamped on the name plates of the motors) are located at the end of a feeder having a resistance of 0.1 ohm on each side. What will be the volts drop in the feeder?

Solution.—Substitute in the formula:

$$E = R \times I = (0.1 + 0.1) \times (20 + 25 + 5) = 0.2 \times 50 = 10 \text{ volts.}$$

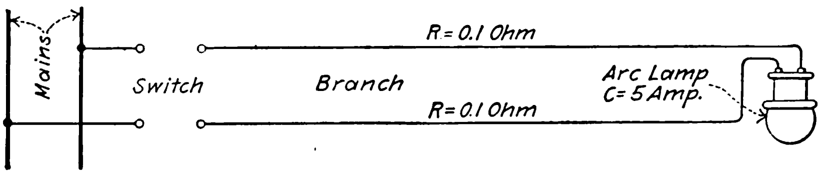


FIG. 16.—Portion of a circuit.

37. Power in direct-current circuits is equal to the product of volts and amperes. (For "power in other alternating-current circuits" see index.) Expressing this as a formula:

$$P = I \times E \qquad P = \frac{E^2}{R} \qquad P = I^2 \times R$$

and also

$$I = \frac{P}{E} \qquad I = \sqrt{\frac{P}{R}} \qquad E = \frac{P}{I} \qquad E = \sqrt{R \times P}$$

$$R = \frac{E^2}{P} \qquad R = \frac{P}{I^2}$$

Wherein, I = current in amperes, E = voltage or electromotive force in volts, R = resistance in ohms and P = the power in watts.

38. In applying the above equations be careful that the values of current, voltage, and resistance used in any one problem all apply to the same circuit or to the same portion of a circuit.

Example.—How many watts are consumed by the incandescent lamp in Fig. 17?

Solution.—Substitute in the formula:

$$P = I \times E = \tfrac{1}{2} \times 110 = 55 \text{ watts.}$$

Example.—How many watts are taken by the motor of Fig. 18? How many kw.? How many h.p.?

Solution.—Substitute in the formula:

$$P = I \times E = 70 \times 220 = 15{,}400 \text{ watts.}$$

$$\text{kw.} = \frac{\text{watts}}{1000} = \frac{15400}{1000} = 15.4 \text{ kw.}$$

$$\text{h.p.} = \frac{\text{watts}}{746} = \frac{15400}{746} = 20.6 \text{ h.p.}$$

Example.—In the transmission line of Fig. 19, what amount of power will be lost in the line wires to the motor?
Solution.—Substitute in the formula:

$$P = I^2 \times R = (40 \times 40) \times (0.3 + 0.3) = 1600 \times 0.6 = 960 \text{ watts.}$$

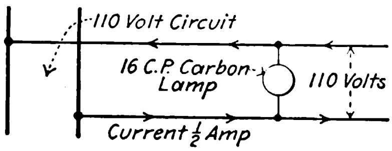


FIG. 17.—Incandescent lamp branch circuit.

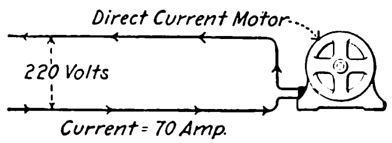


FIG. 18.—Electric motor.

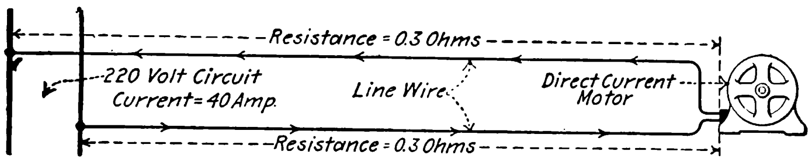


FIG. 19.—Transmission line.

39. Watts, Kilowatts and Horse-power.—One horse-power equals 746 watts, therefore:

$$\text{h.p.} = \frac{\text{watts}}{746} = \text{watts} \times 0.0013 \qquad \text{watts} = \text{h.p.} \times 746$$

$$\text{h.p.} = \frac{\text{kw.}}{0.746} = \text{kw.} \times 1.34 \qquad \text{kw.} = \text{h.p.} \times 0.746.$$

Example.—Watts = 2460, h.p. = ?.
Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{\text{watts}}{746} = \frac{2460}{746} = 3.3 \text{ h.p.}$$

Example.—A motor takes 30 kw. How many horse-power is it taking?
Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{\text{kw.}}{0.746} = \frac{30}{0.746} = 40.2 \text{ h.p.}$$

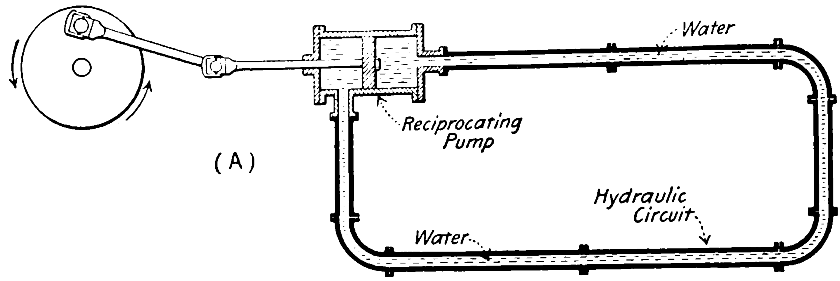
or

$$\text{h.p.} = \text{kw.} \times 1.34 = 30 \times 1.34 = 40.2 \text{ h.p.}$$

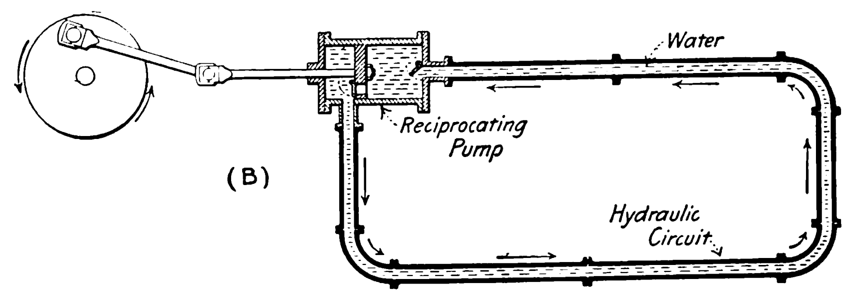
40. An alternating current is one that reverses in direction at regular intervals. In Fig. 20*A* as the hydraulic pump operates, the current of water will flow back and forth through the pipe. This action is analogous to that of an alternating current of electricity. With the arrangement of Fig. 20*B*, corresponding to a direct-current circuit, the current of water will always be in the same direction. For a true analogy the pump of Fig. 20*B* should be of the centrifugal type because with that type the hydraulic pressure is constant. With the reciprocating pump of Fig. 20*B* the water pressure (corresponding to the voltage of an electric circuit) would vary, although it would always be in the same direction. In the ordinary direct-current circuit the pressure is constant.

41. A cycle is a complete set of values through which an alternating current repeatedly passes. See Fig. 21. The expression "60 cycles per second means that the current referred to makes 60 complete cycles in a second. It therefore requires $\frac{1}{60}$ second to complete 1 cycle. See Fig. 21. With a 25-cycle current, $\frac{1}{25}$ second is required to complete 1 cycle. See Fig. 22.

42. The frequency of an alternating current is the number of cycles completed in a second. A frequency of 60 cycles (Fig. 21) is common for lighting and power installations while (Fig. 22) 25 cycles is used for power transmission. When used for lighting,



Hydraulic Analogy to Alternating Current Generator and Circuit.



Hydraulic Analogy to Direct Current Generator and Circuit.

FIG. 20.—Hydraulic analogies.

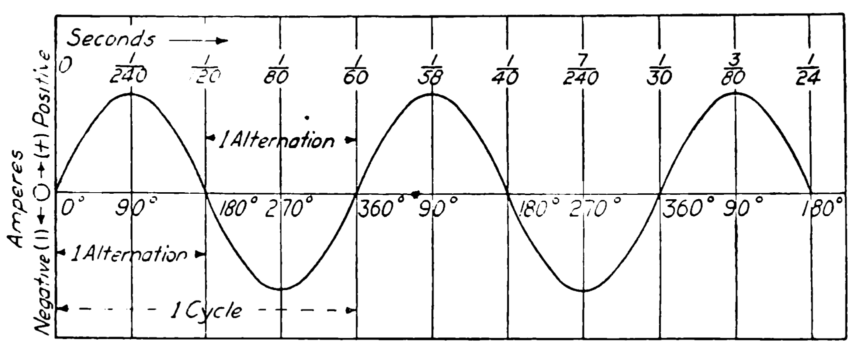


FIG. 21.—Curve of a 60-cycle alternating current.

there is sometimes a flickering of incandescent lamps on 25 cycles. Some arc lamps do not operate well on 25 cycles. Frequencies much lower than 25 cycles cannot be used for incandescent lighting. Some of the older stations generate at 125 or 133 cycles and 15 cycles has been used for railway work.

43. The word "phase," when properly used in alternating-current terminology, refers to time. When two alternating currents are in phase they reach their corresponding zero, maximum and intermediate values at exactly the same instants. If currents or voltages are not in phase they reach corresponding values at different instants.

A three-phase current consists of three different alternating currents out of phase 120 degrees (which are really time degrees—

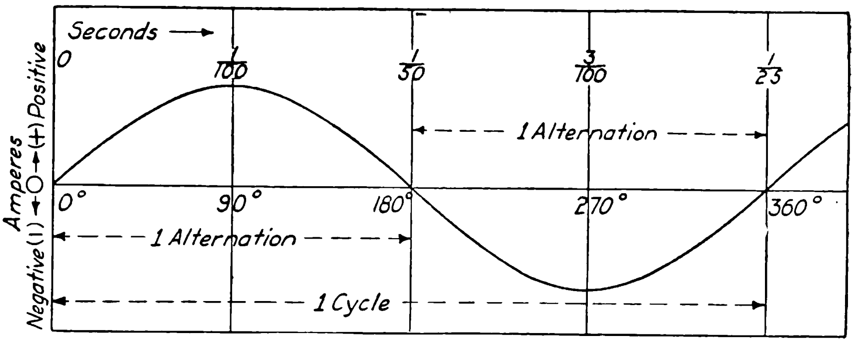


FIG. 22.—Curve of a 25-cycle alternating current.

each degree representing a certain definite amount of time) with each other. A two-phase current consists of two different alternating currents out of phase 90 degrees (which represents a certain definite amount of time) with each other.

Sometimes each of the three wires of a three-phase circuit is called a "phase wire" or for short a "phase." Also, any pair of wires of a polyphase circuit across which the normal voltage of the circuit should exist is sometimes referred to as a "phase" of the circuit.

44. The effective value of an alternating current is that value which will produce the same heating effect as will the same intensity of direct current. Measuring instruments indicate effective values. An effective alternating current of 10 amp. will produce the same heating effect as 10 amp., direct current. A similar statement is true for any other values of alternating and direct currents. Alternating e.m.fs. and currents are constantly changing in value, within a certain range, from instant to instant even if the load is constant. It is not practicable to deal with or indicate with instruments these constantly changing values. Effective values are ordinarily referred to when speaking of alternating currents. The practical man deals almost exclusively with effective values. See Fig. 23. Effective values are sometimes called virtual values.

45. The maximum value of an alternating current or voltage is the greatest value that it attains. This is an instantaneous value. See Fig. 23.

$$\text{Effective value} = 0.707 \times \text{maximum value}$$

$$\text{Maximum value} = \frac{\text{effective value}}{0.707}$$

Example.—What is the effective voltage of a circuit that has a maximum voltage of 156?

Solution.—Substitute in the formula:

Effective value $= 0.707 \times$ maximum value $= 0.707 \times 156 = 110$ volts.

Example.—If a voltmeter on an alternating-current circuit reads 2200, what is the maximum instantaneous voltage?

Solution.—Substitute in the formula:

$$\text{Maximum value} = \frac{\text{Effective value}}{0.707} = \frac{2200}{0.707} = 3110 \text{ volts.}$$

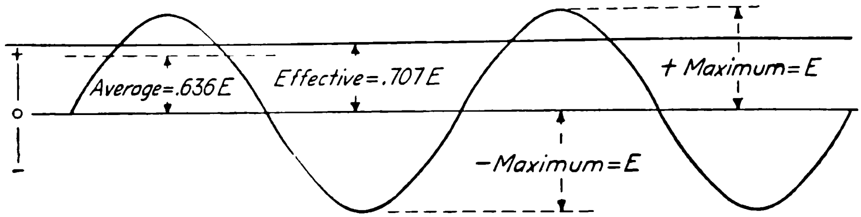


FIG. 23.—Alternating electromotive-force values.

46. The instantaneous value of an alternating current or voltage is its value at some designated instant or, in other words, at some designated point in its cycle.

47. The effect of resistance in alternating-current circuits is the same as in direct-current circuits and Ohm's law is used in calculating its effect. This is true only when there is no inductance or permittance (capacity) in the circuit.

48. The power loss in any conductor traversed by an alternating current or a direct current is

$$P = I^2 \times R \text{ or } I = \sqrt{\frac{P}{R}} \text{ or } R = \frac{P}{I^2}$$

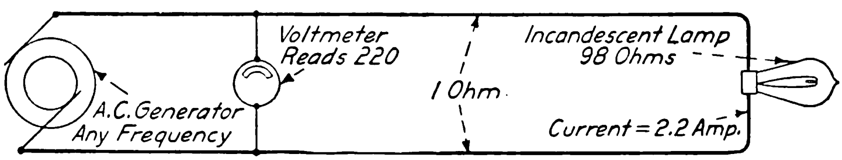


FIG. 24.—Resistance in an alternating-current circuit.

Wherein P = the power lost in the conductor in watts, I = current in amperes in the conductor and R = resistance of conductor in ohms. This rule is perfectly general and applies to all direct current circuits and all alternating-current circuits of ordinary voltages and frequencies. The watts power loss, P, reappears as heat power and heats the conductors. See 304 and 305 for another way of stating this law.

Example.—What is the power loss in the incandescent lamp in Fig. 24?

Solution.—Substitute in the formula:

$$P = I^2 \times R = (2.2 \times 2.2)98 = 4.84 \times 98 = 474 \text{ watts.}$$

Example.—What is the power loss in the inductive winding of Fig. 25, with an alternating current of 3 amp.?

Solution.—Substitute in the formula:

$$R = I^2 \times R = (3 \times 3)7 = 9 \times 7 = 63 \text{ watts.}$$

49. Inductance in alternating-current circuits has very pronounced effects. When an alternating current flows through an inductance a counter e.m.f. is generated. This counter e.m.f. opposes the e.m.f. developed by the generator, with the result that the active e.m.f., that which actually forces current through the circuit, is less than the impressed e.m.f. The amount that it is less depends on the amount of inductance. The subject is too complicated for a full discussion here. The practical man can calculate his circuits with the formulas found in this book without a thorough understanding of the matter.

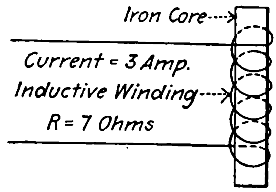


FIG. 25.—Inductive resistance in an alternating-current circuit.

50. Impedance is the name given to that quantity which represents the combined resisting effect of actual (ohmic) resistance and of the inductive resistance (reactance). If impedance in ohms is multiplied by current in amperes the resulting value will be the impressed e.m.f.

51. Power in Alternating-current Circuits.—Power factor is the ratio of true watts to apparent watts in an alternating-current circuit. It is the number by which the apparent power must be multiplied to obtain the real power. Power factor is usually expressed in a per cent. and cannot be greater than 100 per cent.

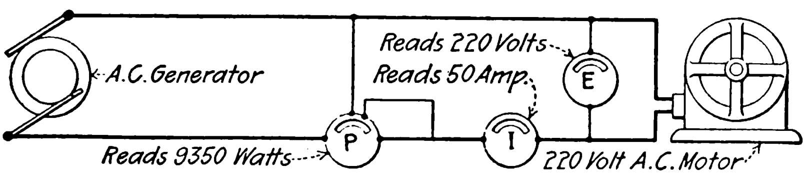


FIG. 26.—Example of power factor.

For Example.—In Fig. 26, which shows a single-phase circuit, the ammeter, I, reads 50 amp. and the voltmeter, E, 220 volts. The apparent power is the product of volts and amperes or $IE = 50 \times 220 = 11000$ watts. But the wattmeter, P, reads 9350 watts. A wattmeter always indicates real or true power. Therefore the power factor (for a single-phase circuit) =

$$\text{power factor} = \frac{\text{true watts}}{\text{apparent watts}} = \frac{9350}{11000} = 0.85 \text{ or } 85 \text{ per cent.}$$

52. The power factor in a non-inductive circuit, one containing resistance only, is always 1, or 100 per cent., that is, the product of volts and amperes in such a circuit gives true power.

53. The power factor in a circuit containing inductance or capacity may be anything between 0 and 1 (0 and 100 per cent.), depending on the amount of inductance or capacity in the circuit.

54. Effects of Low Power Factor (*General Electric Co. publication*).—It is usually considered that the wattless component of a current at low power factor is circulated without an increase of mechanical input over that necessary for actual power requirements. This is inaccurate because internal work or losses due to this extra current are produced and must be supplied by the prime mover. Since these extra losses manifest themselves in heat, the capacity of the machine is reduced. Also wattless components of current

heat the line conductors, just as do energy components, and cause losses in them. The loss in any conductor is always (see 48)

$$P = I^2R$$

where P = the loss in watts, I = the current in amperes in the conductor and R = the resistance in ohms. However, the increase in losses in the generating equipment and line due to low power factor are usually relatively small and it can be said that very little more coal is burned to supply energy at low power factor than at high power factor. This statement is made with the assumption that the efficiency of the prime mover at different loads is constant.

55. Correction of Low Power Factor.—In industrial plants, excessively low power factor is usually due to underloaded induction motors because the power factor of motors is much less at partial loads than at full-load. Where motors are underloaded new motors of smaller capacity should be substituted. (See Induction Motors, Index.) Power factor can be corrected by installing synchronous motors (see Index) which, when overexcited, have the property of neutralizing the wattless or induction components of currents inherent to low power factor.

56. The Cosine of the Angle of Lag is Equal to the Power Factor.—Cosines for different angles can be found in trigonometric tables in handbooks. (See **10**.) The symbol ϕ, a Greek letter, pronounced phi, is often used to designate the angle of lag, hence power factor is sometimes referred to as "Cos ϕ" (Cosine phi). This means the cosine of the angle ϕ.

57. Typical power factors of various kinds of central-station loads as given by F. D. Newbury before the 1911 convention of the N.E.L.A. are given below.

INCANDESCENT LIGHTING WITH SMALL LOWERING TRANSFORMERS.—Power factor, 0.90 to 0.95.

ALTERNATING-CURRENT INCLOSED-ARC LAMPS WITH CONSTANT-CURRENT TRANSFORMERS.—Power factor, from 0.60 to 0.75, depending upon whether the transformers are carrying their rated number of lamps. Average 0.70.

DIRECT-CURRENT METALLIC-ARC LAMPS WITH RECTIFIERS.—Power factor, from 0.55 to 0.70, depending upon whether or not the rectifiers are carrying their rated number of lamps. Average 0.65.

SINGLE-PHASE INDUCTION MOTORS, SQUIRREL-CAGE ROTOR.—$\frac{1}{20}$ h.p. to 1 h.p., power factor, 0.55 to 0.75, average 0.68 at rated load; 1 h.p. to 10 h.p., power factor, 0.75 to 0.86, average 0.82, at rated load.

POLYPHASE INDUCTION MOTORS, SQUIRREL-CAGE ROTOR.—1 h.p. to 10 h.p., power factor, 0.75 to 0.91, average 0.85 at rated load; 10 h.p. to 50 h.p., power factor, 0.85 to 0.92, average 0.89, at rated load.

POLYPHASE INDUCTION MOTORS, PHASE-WOUND ROTORS.—5 h.p. to 20 h.p., power factor, 0.80 to 0.89, average 0.86 at rated load; 20 h.p. to 100 h.p., power factor, 0.82 to 0.90, average 0.87 at rated load.

INDUCTION MOTOR LOADS IN GENERAL.—Power factor, from 0.60 to 0.85, depending on whether motors are carrying their rated loads.

ROTARY CONVERTERS, COMPOUND WOUND.—Power factor at full-load can be adjusted to practically 100 per cent. At light loads it will be lagging, and at overloads slightly leading.

ROTARY CONVERTERS, SHUNT WOUND.—The power factor can be adjusted to any desired value, and will be fairly constant at all loads with the same field rheostat adjustment. Rotary converters, however, should not be operated below 0.95 power factor leading or lagging at full-load or overload.

SMALL HEATING APPARATUS.—This load has the same characteristics as an incandescent-lighting load. The power factor of the load unit is practically unity, but the distributing transformers will lower it to some extent.

ARC FURNACES.—Power factor, 0.80 to 0.90.

INDUCTION FURNACES.—Power factor, 0.60 to 0.70.

ELECTRIC-WELDING TRANSFORMERS.—Power factor, 0.50 to 0.70.

SYNCHRONOUS MOTORS.—Adjustment between practically zero power factor leading to zero power factor lagging.

The author made the following general statements regarding probable power factors: (1) Operating power factors above 0.95 will be obtained only when practically all of the load is synchronous motors or converters which may be operated at practically unity power factor. Even with this character of load the generators should be capable of operating satisfactorily at 0.93 power factor to provide for unforeseen contingencies. (2) Power factors of 0.90 to 0.95 can be safely predicted only when the load is entirely incandescent lighting or heating, or if a large non-inductive load, such as synchronous motors or converters, is used with a smaller proportion of inductive motor load. (3) For the average central-station load, consisting of lighting and motor service, a power factor of 0.80 should be assumed. (4) A power factor of 0.70 should be assumed for a plant having a large proportion of induction motors, arc lighting, electric furnaces or electric welding load.

58. Kilowatts and Kilovolt-amperes (*General Electric Company*).—The term kilowatt (kw.) indicates the measure of power which is all available for work. Kilovolt-amperes (kva.) indicate the measure of apparent electrical power made up of two components, an energy component and a wattless or induction component. Kw. indicates real power and kva. apparent power. They are identical only when current and voltage are in phase, that is, when the power factor is 1. Ammeters and voltmeters indicate total effective current and voltage regardless of the power factor, while a wattmeter indicates the effective product of the instantaneous values of electromotive force and current. A wattmeter, then, indicates real power.

Standard guarantees on alternating-current generators are made on the basis of loads at 100 per cent. power factor, because this has seemed to be the best method, but it must not be inferred that a given generator will deliver its rated power output at all power factors. The generator rating in kw. will be reduced in proportion to the power factor and probably in a greater ratio if the power factor is very low. In general, a generator will carry a kva. load to the extent of its normal kw. rating if the power factor of the load

is not below 80 per cent. The actual power output, however, must be reduced in proportion to the power factor. The method of rating alternating-current generators by kva. instead of by kw. is now in general use.

In discussing an alternating-current load, it is well to state it in terms of kw., power factor and kva. thus: 200 kw., 80 per cent. power factor (250 kva.). This shows that the current in the circuit corresponds to 250 kva. and heats the generator and conductors to that extent, but that only 200 kw. is available for doing work.

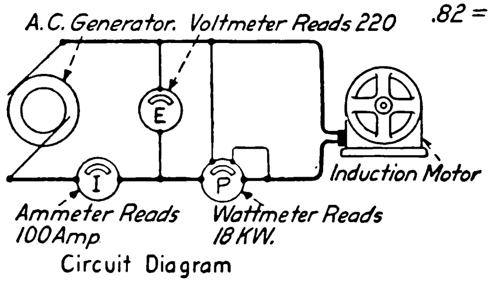
59. For a single-phase circuit the relations between kilowatts and kilovolt-amperes are:

$$\text{kilovolt-amperes} = \frac{\text{volts} \times \text{amperes}}{1000} \qquad \text{or kva.} = \frac{E \times I}{1000}$$

$$\text{kw.} = \text{kva.} \times \text{power factor} \qquad \text{kva.} = \frac{\text{kw.}}{\text{power factor}}$$

$$\text{power factor} = \frac{\text{kw.}}{\text{kva.}}$$

For an example see Fig. 27.



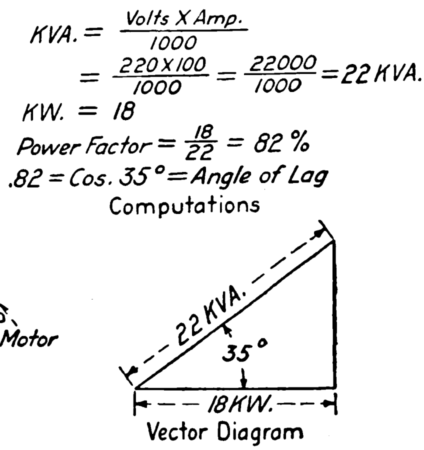


FIG. 27.—Illustrating the distinction between kw. and kva.

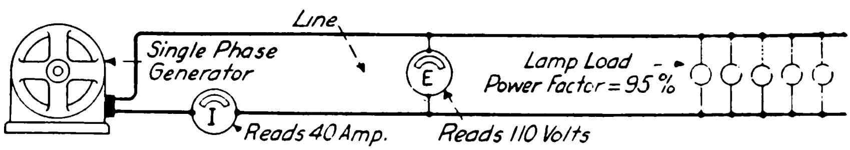


FIG. 28.—A power factor problem.

59A. For a single-phase circuit the following equations show the relations between power, current, voltage and power factor.

$$I = \frac{P}{E \times p.f.} \qquad E = \frac{P}{I \times p.f.} \qquad P = E \times I \times p.f. \qquad p.f. = \frac{P}{E \times I}$$

Wherein, I = current in amperes, P = power in watts, E = pressure in volts between lines and $p.f.$ = power factor.

Examples.—Figs. 27 and 28 show examples of the application of the above equations. The product of volts and amperes (EI) is called volt-amperes; see above paragraph.

Example.—In the circuit of Fig. 28, what is the actual load in watts? In kilowatts? Current = 40 amp., voltage at load = 110, power factor of load = 95 per cent.

Solution.—Substitute in the formula

$$P = E \times I \times p.f. = 110 \times 40 \times 0.95 = 4{,}180 \text{ watts}$$

$$\text{kw.} = \frac{\text{watts}}{1000} = \frac{4180}{1000} = 4.18 \text{ kw.}$$

60. To find amperes in the line in single-phase circuits (*Westinghouse Diary*) multiply the power in kilowatts by the value, for the proper voltage and power factor, shown in table 61.

61. Amperes per Phase per Kilowatt, Single-phase Circuits

Volts	Power factor			
	100 per cent.	90 per cent.	80 per cent.	70 per cent.
110	9.09	10.01	11.36	12.98
220	4.54	5.05	5.68	6.49
440	2.27	2.52	2.84	3.24
1,100	0.909	1.01	1.136	1.298
2,200	0.454	0.505	0.568	0.649

62. A two-phase current consists of two currents that differ in phase by 90°. See curves of Fig. 29. If two sets of coils are arranged on an armature (Fig. 29) so that the e.m.f. in one set will

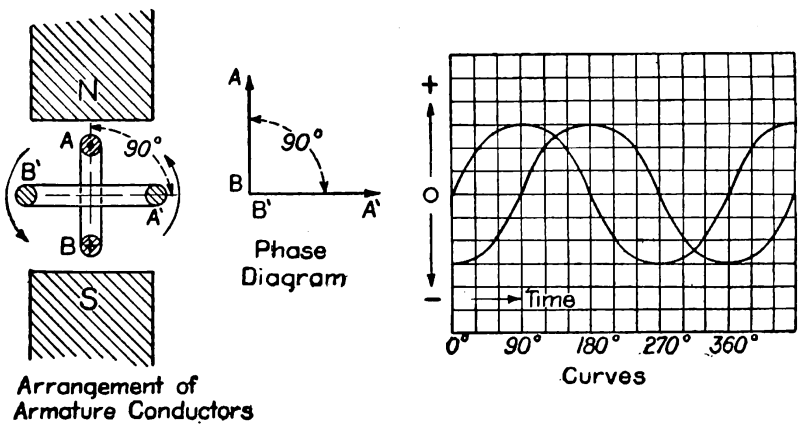


FIG. 29.—Diagrams for two-phase currents.

attain its maximum value 90° later than that in the other, the e.m.fs. will force two-phase currents through an external circuit. Instead of being on the same armature each of the sets of coils might be on different armatures which are so mechanically connected together as to preserve the 90° phase relation. (See section on "Motors and Generators" for information on practical machines.)

63. Application of the Two-phase System.—Several years ago certain engineers advocated two-phase generators and distributing systems in preference to three-phase, as it was believed that unbalanced load on the phases would have less adverse effect on the performance of the two-phase equipment. Recent experience

seems to indicate that the three-phase system is preferable to the two-phase for both transmission and distribution. It is seldom that two-phase equipment is now purchased except for additions to existing two-phase installations. See Par. 243 for relative weights of copper for different systems.

64. **To find amperes per phase in two-phase circuits** (*Westinghouse Diary*) multiply the load in kw. by the value in the following table corresponding to the proper power factor and voltage.

65. **Amperes per Phase per Kilowatt, Two-phase Circuits**

Volts	Power factor			
	100 per cent.	90 per cent.	80 per cent.	70 per cent.
110	4.54	5.04	5.67	6.48
220	2.27	2.52	2.83	3.24
440	1.13	1.26	1.41	1.62
1,100	0.454	0.504	0.567	0.648
2,200	0.227	0.252	0.283	0.324

66. **A three-phase current** consists of three alternating currents that differ in phase by 120°, as indicated in Fig. 30. If three coils be arranged 120° apart on an armature (Fig. 30) rotated in a mag-

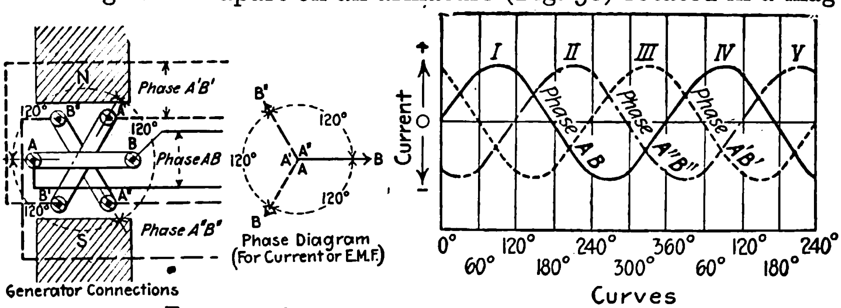


FIG. 30.—Principles of three-phase circuits.

netic field and connected (through collector rings not shown) each to an external circuit, an alternating e.m.f. will be impressed by each coil on its external circuit. The e.m.fs. will differ in phase by 120° and therefore will constitute a three-phase e.m.f. The currents in the circuits will constitute a three-phase current. Three single-phase generators, if mechanically coupled together so as to maintain a 120° phase relation, would produce a three-phase e.m.f. Practical three-phase generators usually have more than two poles and consequently have more coils than indicated in Fig. 30. Modern alternating-current generators have revolving fields and stationary armatures.

66A. **Coil Connections.**—Fig. 31 shows four methods of connecting three-phase generator (or other apparatus) coils and the external circuits for each. *Method I*, although it would work, is seldom if ever used for economic reasons hereinafter given. It shows the elementary three-phase circuit and illustrates the principle. Each of the three-phases would carry a current differing in phase by 120°

from the currents in the other two. One common return, as shown at *II* can be substituted for the three return wires of *I*. Now with a balanced load, *i.e.*, one loading each of the phases equally, this return wire would carry no current, hence it is usually omitted (**star** or **Y-connection** of *III*). In *IV* is shown the delta connection.

67. The voltage and current relations in a star or Y-connected three-phase circuit are indicated in Fig. 32. Although the armature coils of the generator are said to be 120° apart, when they are Y-connected as shown in *I*, the e.m.fs. in any two are 60° apart and

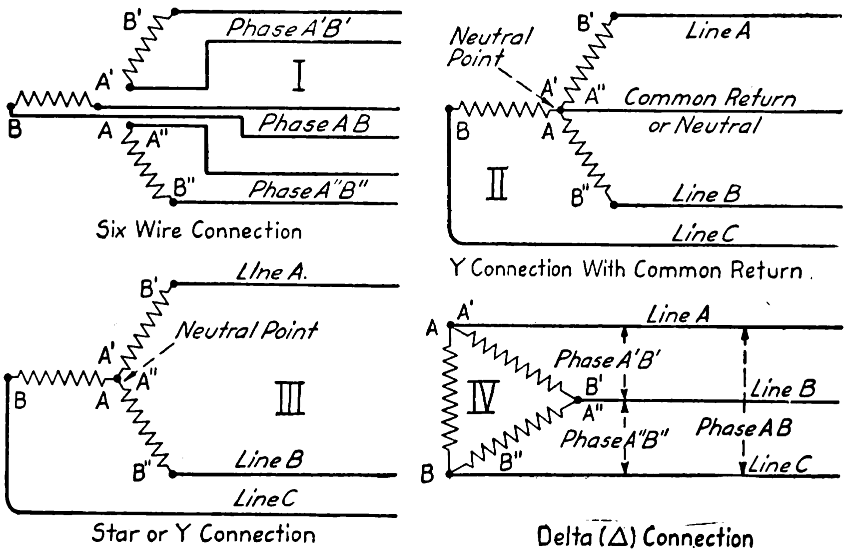


FIG. 31.—Connections for three-phase generator windings.

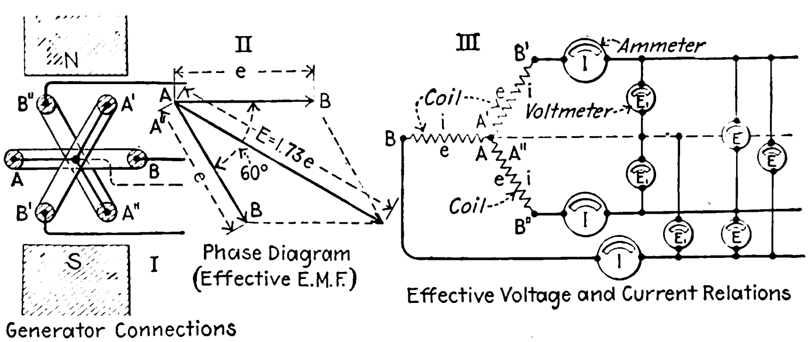


FIG. 32.—Properties of a star, or Y-connected three-phase circuit.

these e.m.fs. are added as shown in the *phase diagram II*. The sum of the voltages of any two coils is then equal to $\sqrt{3}$ or 1.73 times the voltage developed in 1 coil. The following formulas show the relation of voltage and current in the circuit. (All are effective values and balance is assumed.) See Fig. 32.

$$I = i$$
$$E = E_1 \times \sqrt{3} = E_1 \times 1.73$$
$$E_1 = \frac{E}{\sqrt{3}} = \frac{E}{1.73} = E \times 0.577 \text{ or approximately } E_1 = 0.58E$$
$$E_1 = e$$

Wherein I = amp. per phase in the line, i = amp. per phase in each coil, E = volts between phase wires on the line, e = volts across each group of armature coils connected across each phase, E_1 = volts between phase wires and neutral. The coils in Fig. 32 *III* may represent the phase windings of a three-phase generator or trans-

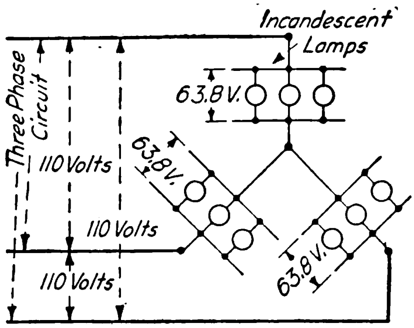


FIG. 33.—Y-connected incandescent lamps.

former, or each coil may represent a transformer or other device, three of which are Y-connected on a three-phase line.

Example.—What will be the voltage across each of the incandescent lamps, which are Y-connected across a 110-volt, three-phase circuit, in Fig. 33?

Solution.—Substitute in the formula:

$$E_1 = 0.58E = 0.58 \times 110 = 63.8 \text{ volts.}$$

68. Relations for a delta (Δ) connected, three-phase circuit are shown in Fig. 34. When armature coils of a generator, see *I*, are connected as indicated, the voltages generated in them are 120°

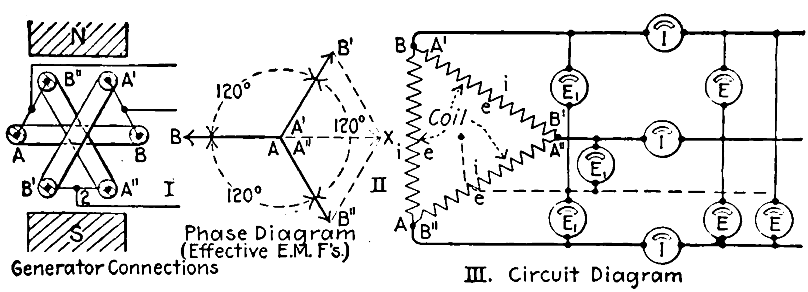


FIG. 34.—Properties of a Δ (delta)-connected, three-phase circuit.

apart. It would appear that the current might flow around through the coils and not into the external circuit, but it is evident from the phase diagram, *II*, that the sum of the effective voltages generated by two of the coils is equal and opposite to that of the third. Hence

instead of tending to force current around internally, the voltages tend to force current out into the line. The following formulas indicate the relations of the voltages and currents. (All are effective values and the circuit is assumed to be balanced.) See Fig. 34.

$$I = i \times \sqrt{3} = i \times 1.73$$

$$i = \frac{I}{\sqrt{3}} = I \times 0.577 \text{ or approximately } i = I \times 0.58$$

$$E = e$$

$$E_1 = \frac{e}{\sqrt{3}} = e \times 0.577 \text{ or approximately } E_1 = e \times 0.58$$

Wherein the symbols have the same meanings as in the preceding paragraph.

Each coil (Fig. 34) may represent the phase windings of a three-phase transformer or generator or each coil may represent a transformer or other device three of which are Δ-connected on a three-phase line.

Example.—Each of the groups of incandescent lamps, delta-connected across the 110-volt, three-phase circuit of Fig. 35, takes 10 amp. What is the current in the line wires?

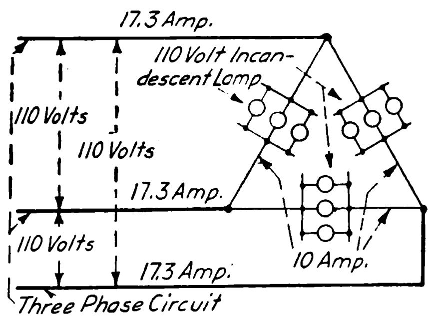


FIG. 35.—Delta (Δ)-connected incandescent lamps.

Solution.—Substitute in the formula:

$$I = i \times 1.73 = 10 \times 1.73 = 17.3 \text{ amp.}$$

69. Relations of voltage, current and power that apply to any three-wire three-phase circuit either Δ- or Y-connected.—Refer to Fig. 36 for a key to the letters that appear in the following formulas.

For a non-inductive load:

$$I = \frac{P}{E \times \sqrt{3}} = \frac{0.577 \times P}{E} \text{ or approximately } = \frac{0.58 \times P}{E}$$

$$E = \frac{P}{I \times \sqrt{3}} = \frac{0.577 \times P}{I} \text{ or approximately } = \frac{0.58 \times P}{I}$$

$$P = E \times I \times \sqrt{3} = 1.73 \times E \times I$$

For an inductive load:

$$p.f. = \frac{P}{1.73 \times I \times E} = \frac{0.577 \times P}{I \times E} \text{ or approximately } = \frac{0.58 \times P}{I \times E}$$

$$E = \frac{P}{p.f \times 1.73 \times I} = \frac{0.577 \times P}{p.f. \times I} \text{ or approximately } = \frac{0.58 \times P}{p.f. \times I}$$

$$I = \frac{P}{p.f. \times 1.73 \times E} = \frac{0.577 \times P}{p.f. \times E} \text{ or approximately } = \frac{0.58 \times P}{p.f. \times E}$$

$$P = 1.73 \times E \times I \times p.f.$$

Wherein I = line current in amperes, P = the power transmitted in watts, E = voltage across lines and $p.f.$ is the power factor of the circuit.

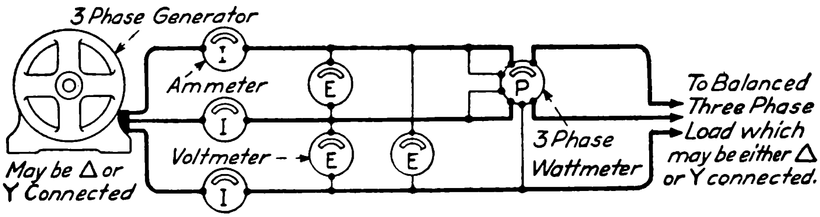


FIG. 36.—Relations for any (Δ- or Y-connected), three-phase circuit.

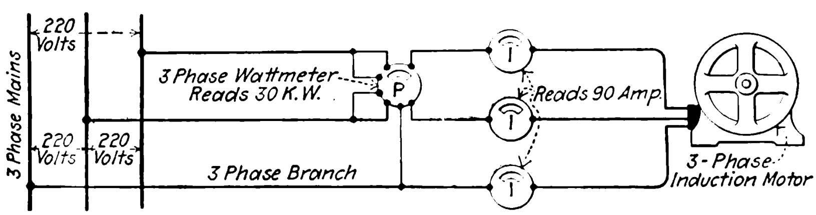


FIG. 37.—Motor on a three-phase circuit.

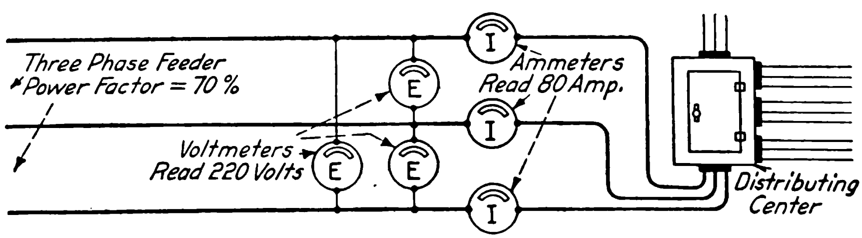


FIG. 38.—Load on a three-phase circuit.

Example.—What is the power factor in the 220-volt circuit to the motor in Fig. 37? The three ammeters each indicate 90 amp. and the three-phase wattmeter indicates 30 kw. (30,000 watts).

Solution.—Substitute in the formula:

$$p.f. = \frac{0.577 \times P}{I \times E} = \frac{0.577 \times 30{,}000}{90 \times 220} = \frac{17{,}310}{19{,}800} = 0.88 = 88 \text{ per cent. power}$$

factor.

Example.—The power factor on the feeder of Fig. 38 is known to be 70 per cent. The current in each line is 80 amp. and the voltage across each phase is 220. What actual power is being delivered to the panel box?

Solution.—Substitute in the formula:

$$P = 1.73 \times E \times I \times p.f. = 1.73 \times 220 \times 80 \times 0.70 = 21313.6 \text{ watts}$$

$$kw. = \frac{\text{watts}}{1{,}000} = \frac{21313.6}{1{,}000} = 21.3 \text{ kw.}$$

Examples.—Fig. 39 shows some numerical examples of voltage and current relations in a three-phase circuit. For convenience the voltage on the main is taken as 100. For any other voltage the values given in the illustration would vary proportionally. For 200 volts they would be twice as great as

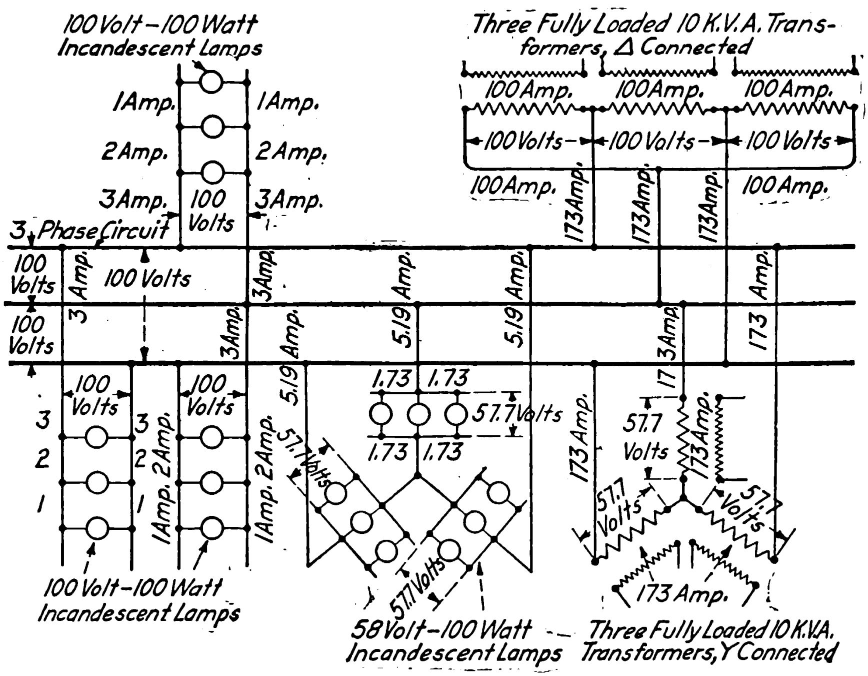


FIG. 39.—Examples of current and voltage relations with three-phase circuits.

shown, for 220 volts they would be 2.2 times as great, etc. Note that when a group of three devices is connected in Δ, each device has line voltage impressed on it and must be designed for that voltage; the current in the line will be 1.73 times the current through the device. When Y-connected, each of the three devices must be designed for $\frac{1}{1.73}$ or 0.577 times the line-voltage and the line current will be the same as the current through it.

70. To find amperes per phase in three-phase circuits multiply the load in kw. by the value in table 71 corresponding to the proper power factor and voltage.

71. Amperes per Kilowatt in Each Leg of a Balanced

Power factor	Volts between						
	100	110	125	200	220	250	440
50	11.55	10.50	9.24	5.77	5.25	4.62	2.62
51	11.32	10.29	9.06	5.66	5.15	4.53	2.57
52	11.10	10.09	8.88	5.55	5.05	4.44	2.52
53	10.89	9.90	8.72	5.44	4.95	4.36	2.47
54	**10.69**	**9.72**	**8.55**	**5.34**	**4.86**	**4.28**	**2.43**
55	10.50	9.54	8.40	5.25	4.77	4.20	2.38
56	10.31	9.37	8.25	5.15	4.69	4.12	2.34
57	10.13	9.21	8.10	5.06	4.60	4.05	2.30
58	9.96	9.05	7.96	4.98	4.53	3.98	2.26
59	**9.79**	**8.90**	**7.83**	**4.89**	**4.45**	**3.92**	**2.22**
60	9.62	8.75	7.70	4.81	4.37	3.85	2.18
61	9.46	8.61	7.57	4.73	4.30	3.79	2.15
62	9.31	8.47	7.45	4.65	4.23	3.72	2.11
63	9.17	8.33	7.33	4.58	4.16	3.67	2.08
64	**9.02**	**8.20**	**7.22**	**4.51**	**4.10**	**3.61**	**2.05**
65	8.88	8.07	7.10	4.44	4.03	3.55	2.02
66	8.75	7.95	7.00	4.37	3.97	3.50	1.99
67	8.62	7.83	6.89	4.31	3.91	3.45	1.96
68	8.49	7.72	6.79	4.24	3.86	3.40	1.93
69	**8.37**	**7.61**	**6.69**	**4.18**	**3.80**	**3.34**	**1.90**
70	8.25	7.50	6.60	4.13	3.75	3.30	1.87
71	8.13	7.39	6.50	4.06	3.69	3.25	1.85
72	8.02	7.29	6.41	4.01	3.64	3.20	1.83
73	7.91	7.19	6.33	3.95	3.59	3.16	1.80
74	**7.80**	**7.09**	**6.24**	**3.90**	**3.54**	**3.12**	**1.77**
75	7.70	7.00	6.16	3.85	3.50	3.08	1.75
76	7.60	6.91	6.08	3.80	3.45	3.04	1.73
77	7.50	6.82	6.00	3.75	3.41	3.00	1.70
78	7.40	6.73	5.92	3.70	3.36	2.96	1.68
79	**7.31**	**6.64**	**5.85**	**3.65**	**3.32**	**2.92**	**1.66**
80	7.22	6.56	5.77	3.61	3.28	2.88	1.64
81	7.13	6.48	5.70	3.56	3.24	2.85	1.62
82	7.04	6.40	5.63	3.52	3.20	2.82	1.60
83	6.96	6.32	5.56	3.48	3.16	2.78	1.58
84	**6.87**	**6.25**	**5.50**	**3.43**	**3.12**	**2.75**	**1.56**
85	6.79	6.17	5.43	3.39	3.09	2.72	1.54
86	6.71	6.10	5.37	3.35	3.05	2.68	1.52
87	6.64	6.03	5.31	3.32	3.01	2.66	1.51
88	6.56	5.96	5.25	3.28	2.98	2.62	1.49
89	**6.49**	**5.90**	**5.19**	**3.24**	**2.95**	**2.59**	**1.47**
90	6.41	5.83	5.13	3.20	2.91	2.56	1.46
91	6.34	5.77	5.08	3.17	2.88	2.54	1.44
92	6.28	5.70	5.02	3.14	2.85	2.51	1.42
93	6.21	5.64	4.97	3.10	2.82	2.48	1.41
94	**6.14**	**5.58**	**4.91**	**3.07**	**2.79**	**2.46**	**1.39**
95	6.08	5.52	4.86	3.04	2.76	2.43	1.38
96	6.01	5.47	4.81	3.00	2.73	2.40	1.37
97	5.95	5.41	4.76	2.97	2.70	2.38	1.35
98	5.89	5.36	4.71	2.94	2.68	2.35	1.34
99	**5.83**	**5.30**	**4.66**	**2.91**	**2.65**	**2.33**	**1.32**
100	5.75	5.25	4.62	2.88	2.63	2.31	1.31

72. Methods of determining the power factor of circuits are described in the division of this section subjected "Measurements, Testing and Instruments."

73. Skin Effect.—When an alternating current flows through a conductor there is an inductive action whereby the current in the conductor is forced toward its surface. The current density is greater at the surface than at the center and under certain condi-

Three-phase Line (*Power*, Nov. 21, 1911)

any two wires							Power factor
500	550	1,100	1,150	2,200	2,300	6,600	
2.31	2.10	1.050	1.004	0.525	0.502	0.175	50
2.26	2.06	1.029	0.985	0.515	0.492	0.172	51
2.22	2.02	1.009	0.966	0.505	0.483	0.168	52
2.18	1.98	0.990	0.947	0.495	0.474	0.165	53
2.14	**1.94**	**0.972**	**0.930**	**0.486**	**0.465**	**0.162**	**54**
2.10	1.91	0.954	0.913	0.477	0.456	0.159	55
2.06	1.87	0.937	0.897	0.469	0.448	0.156	56
2.03	1.84	0.921	0.881	0.460	0.440	0.153	57
1.99	1.81	0.905	0.866	0.453	0.433	0.151	58
1.96	**1.78**	**0.890**	**0.851**	**0.445**	**0.425**	**0.148**	**59**
1.92	1.75	0.875	0.837	0.437	0.418	0.146	60
1.89	1.72	0.861	0.823	0.430	0.411	0.143	61
1.86	1.69	0.847	0.810	0.423	0.405	0.141	62
1.83	1.67	0.833	0.797	0.416	0.398	0.139	63
1.80	**1.64**	**0.820**	**0.784**	**0.410**	**0.392**	**0.137**	**64**
1.78	1.61	0.807	0.772	0.403	0.386	0.134	65
1.75	1.59	0.795	0.761	0.397	0.380	0.132	66
1.72	1.57	0.783	0.749	0.391	0.374	0.130	67
1.70	1.54	0.772	0.738	0.386	0.369	0.129	68
1.67	**1.52**	**0.761**	**0.728**	**0.380**	**0.364**	**0.127**	**69**
1.65	1.50	0.750	0.717	0.375	0.359	0.125	70
1.63	1.48	0.739	0.707	0.369	0.354	0.123	71
1.60	1.46	0.729	0.697	0.364	0.349	0.121	72
1.58	1.44	0.719	0.688	0.359	0.344	0.120	73
1.56	**1.42**	**0.709**	**0.678**	**0.354**	**0.339**	**0.118**	**74**
1.54	1.40	0.700	0.669	0.350	0.334	0.117	75
1.52	1.38	0.691	0.661	0.345	0.330	0.115	76
1.50	1.36	0.682	0.652	0.341	0.326	0.114	77
1.48	1.35	0.673	0.644	0.336	0.322	0.112	78
1.46	**1.33**	**0.664**	**0.636**	**0.332**	**0.318**	**0.111**	**79**
1.44	1.31	0.656	0.628	0.328	0.314	0.109	80
1.43	1.30	0.648	0.620	0.324	0.310	0.108	81
1.41	1.28	0.640	0.612	0.320	0.306	0.107	82
1.39	1.26	0.632	0.605	0.316	0.302	0.105	83
1.37	**1.25**	**0.625**	**0.598**	**0.312**	**0.299**	**0.104**	**84**
1.36	1.23	0.617	0.591	0.309	0.295	0.103	85
1.34	1.22	0.610	0.584	0.305	0.292	0.102	86
1.33	1.21	0.603	0.577	0.301	0.288	0.100	87
1.31	1.19	0.596	0.570	0.298	0.285	0.099	88
1.30	**1.18**	**0.590**	**0.564**	**0.295**	**0.282**	**0.098**	**89**
1.28	1.17	0.583	0.558	0.291	0.279	0.097	90
1.27	1.15	0.577	0.552	0.288	0.276	0.096	91
1.26	1.14	0.570	0.546	0.285	0.273	0.095	92
1.24	1.13	0.564	0.540	0.282	0.270	0.094	93
1.23	**1.12**	**0.558**	**0.534**	**0.279**	**0.267**	**0.093**	**94**
1.22	1.10	0.552	0.528	0.276	0.264	0.092	95
1.20	1.09	0.547	0.523	0.273	0.261	0.091	96
1.19	1.08	0.541	0.518	0.270	0.259	0.090	97
1.18	1.07	0.536	0.512	0.268	0.256	0.089	98
1.17	**1.06**	**0.530**	**0.507**	**0.265**	**0.254**	**0.088**	**99**
1.16	1.05	0.525	0.502	0.263	0.252	0.087	100

tions there may be practically no current flowing along the axis of the conductor. Although skin effect and self induction both originate from the same magnetic field they are not otherwise related. Since it increases voltage drop and energy loss, skin effect amounts to an increase in resistance and is so considered. The following table gives values by which actual resistances of conductors must be multiplied to obtain their virtual resistances

to alternating currents. Non-conducting cores are sometimes placed in the centers of large cables for alternating currents so that all of the metal will be worked at the best possible efficiency. See Table 182 for such conductors.

74. **Skin effect in conductors of magnetic materials** is much greater than in those of non-magnetic materials due to the stronger magnetic field that a given current will set up in a magnetic metal. See the tables in the *Standard Handbook.*

75. **Skin effect in stranded conductors** is, for all practical purposes, equal to that in solid conductors of equal diameters. Table 76 gives values for solid conductors.

76. **Skin Effect Factors For Copper Wire.**—Values by which the real (ohmic) resistance of solid, round, copper conductors must be multiplied to obtain their virtual resistance to alternating currents of commercial frequencies.

Frequency	Factors for different copper wire sizes (B. & S. Gage) and diameters							
	4	3	2	1	0	00	000	0000
25 cycles..	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.001
60 cycles..	1.000	1.000	1.000	1.000	1.001	1.002	1.005	1.006
130 cycles..	1.000	1.001	1.002	1.005	1.008	1.010	1.017	1.027

Frequency	Factors for different copper wire sizes (B. & S. Gage) and diameters.—*Continued*							
	$\frac{1}{2}''$	$\frac{3}{4}''$	$1''$	$1\frac{1}{8}''$	$1\frac{1}{4}''$	$1\frac{1}{2}''$	$1\frac{3}{4}''$	$2''$
25 cycles..	1.002	1.007	1.020	1.035	1.053	1.098	1.170	1.265
60 cycles..	1.008	1.040	1.111	1.168	1.239	1.420	1.622	1.826
130 cycles..	1.039	1.156	1.397	1.545	1.694	1.983	2.272	2.560

Example.—A No. 000 wire 1,000 ft. long has an actual resistance of 0.0489 ohms. Its resistance to a 130-cycle alternating current would be $0.0489 \times 1.017 = 0.0497$ ohms.

77. **Self induction** is the phenomena whereby an e.m.f. is induced in a conductor by a change of current in the conductor itself. Such an e.m.f. always produces currents and magnetic fields in such a direction that they tend to oppose the inducing currents and fields.

78. **Work** is the overcoming of mechanical resistance through a certain distance. Work is measured by the product of the mechanical resistance times the space through which it is overcome. Work is measured by the product of the moving force times the distance through which the force acts in overcoming the resistance. Work is, therefore, measured in foot-pounds (ft-lb.).

Example.—What work is done if a weight of 6 lb. is lifted through a distance of 8 ft.?

Solution.—Work = ft. × lb. = 8 × 6 = 48 ft-lb.

Example.—If 20 gal. of water are pumped to a vertical height of 32 ft. what work has been done?

Solution.—A gallon of water weighs 8 lb. therefore

Work = ft. × lb. = 32 × (20 × 8) = 5,120 ft-lb.

Example.—If the piston in a steam engine travels, during a certain interval, $1\frac{1}{2}$ ft. and the total pressure on the piston is 40,000 lb., what work is done during the interval?

Solution.—Work = ft. × lb. = 1.5 × 40,000 = 60,000 ft-lb.

79. **Energy** is capacity for doing work. Any body or medium which is of itself capable of doing work is said to possess energy. A coiled clock spring possesses energy because, in unwinding, it can do work. A moving projectile possesses energy because it can overcome the resistance offered by the air, by armor plate, etc., and thus do work. A charged storage battery possesses energy because it can furnish electricity to operate a motor. Energy can be expressed in foot-pounds.

80. **Energy of one sort may be transformed into energy of another sort.** Heat energy in coal may be transformed (with a certain loss) with a boiler, a steam engine and a generator, into electrical energy. The energy possessed by a stream of falling water may be transformed, with a waterwheel and generator, into electrical energy. There is a definite numerical relation between different sorts of energy. Thus 1 B.T.U., the unit of heat energy = 778 ft-lb. In electrical units, energy is expressed in watt-hours or kilowatt-hours.

81. **A kilowatt-hour** represents the energy expended if work is done for one hour at the rate of 1 kw.

82. **A horse-power-hour** represents the energy expended if work is done for one hour at the rate of 1 h.p.

83. **Power** is rate of doing work. The faster work is done the greater the power that will be required to do it. For example, if a 10-h.p. motor can raise a loaded elevator a certain distance in 2 minutes a 20-h.p. motor will (approximately) be required to raise it the same distance in 1 minute.

84. **The horse-power** is the unit of power and is about equal to the power of a strong horse to do work for a short interval. Numerically a horse-power is 33,000 ft-lb. per minute, = 550 ft-lb. per second, = 1,980,000 ft-lb. per hour. Expressed as a formula:

$$\text{h.p.} = \frac{L \times W}{33{,}000 \times t} = \frac{\text{foot-pounds per minute}}{33{,}000}$$

Wherein, h.p. = horse-power, L = distance, in feet, through which W is raised or overcome; W = weight, in pounds, of the thing lifted or the push or pull in pounds of the force overcome, and t is the time in minutes required to move or overcome the weight W through the distance L.

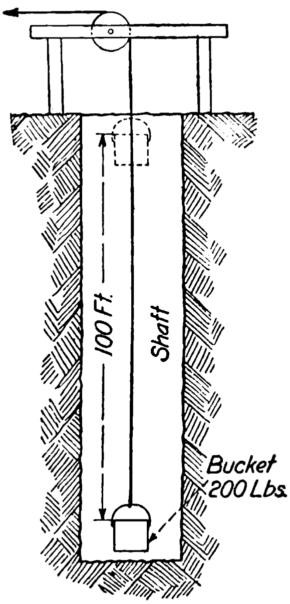


FIG. 40.—Bucket in shaft.

Example.—What horse-power is required in raising the load and bucket, weighing 200 lb., shown in Fig. 40, from the bottom to the top of the shaft, a distance of 100 ft., in 2 minutes?

Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{L \times W}{33{,}000 \times t} = \frac{100 \times 200}{33{,}000 \times 2} = 0.3 \text{ h.p.}$$

Example.—What average horse-power is required while moving the box loaded with stone, in Fig. 41, from *A* to *B*, 650 ft., in 3 minutes? It takes a horizontal pull of 150 lb. to move the box.

Solution.—Substitute in the formula:

$$\text{h.p.} = \frac{L \times W}{33{,}000 \times t} = \frac{650 \times 150}{33{,}000 \times 3} = 0.98 \text{ h.p.}$$

85. Electric power is expressed numerically in watts or in kilowatts. A kilowatt is 1,000 watts. The watt represents the amount of power in a circuit when the current in that circuit is 1 amp. and the electromotive force is 1 volt.

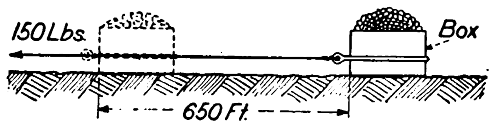


FIG. 41.—Moving loaded box.

86. Efficiency is the name given to the *ratio of output to input.* No machine gives out as much energy or power as is put into it. There are some losses in even the most perfectly constructed machines. Efficiency is usually expressed as a percentage, thus, "the efficiency of a certain motor is 80 per cent." This means that only 80 per cent. of the energy or power received by the motor as electricity is delivered by the motor at the pulley. Another way of stating the definition is:

$$\text{efficiency} = \frac{\text{output}}{\text{input}}$$

It follows that

$$\text{input} = \frac{\text{output}}{\text{efficiency}}$$

and, $\text{output} = \text{input} \times \text{efficiency}.$

When using the formulas, output and input must be expressed in the same units.

87. Output is the useful energy delivered by a machine and **input** is the energy supplied to a machine.

Example.—If 45 kw. is supplied to a motor and its output is found to be 54.2 h.p., what is its efficiency?

Solution.—Since 1 h.p. = 0.746 kw., 54.2 h.p. = 54.2 × 0.75 = 40.6 kw. Then substituting in the formula

$$\text{efficiency} = \frac{\text{output}}{\text{input}} = \frac{40.6}{45} = 0.90 = 90 \text{ per cent. efficiency.}$$

88. Torque is the measure of the tendency of a body to rotate. It is the measure of a turning or twisting effort and it is usually expressed in pounds-foot or in pounds force at a given radius. Torque may exist even if there be no motion. Thus, in Fig. 42, the torque at the circumference of the drum is 50 lb. so long as the weight is supported, whether the drum be moving or standing still. It is assumed that the hoisting rope has no weight. Torque is sometimes expressed as the product of the force introducing the tendency to rotate times the distance from the center of rotation to the point of application of the force. For instance, in Fig. 43 the torque tending to turn the cylinder in the brick wall would be 100 × 12 = 1,200 lb-ft. (In some text-books this would, inaccurately, be expressed as 1,200 ft-lb.) The cylinder cannot turn and no work could be done, yet there is

torque. Probably the most preferable way of expressing the torque is in terms of pressure (or force) and radius. Thus: "100 lb. force at 12 ft. radius." Ordinarily the expression is given for unit or 1-ft. radius. Then, for the case of Fig. 43, the torque would be 1,200 lb. at 1 ft. radius. Because of the fact that many **writers and engineers erroneously express units of both work and torque** in foot-pounds, a confusion sometimes exists regarding the distinction between the two. Work (see **78**) is properly expressed in foot-pounds (ft-lb.), while torque should be expressed in pounds-feet (lb-ft.), or preferably in pounds at a given radius.

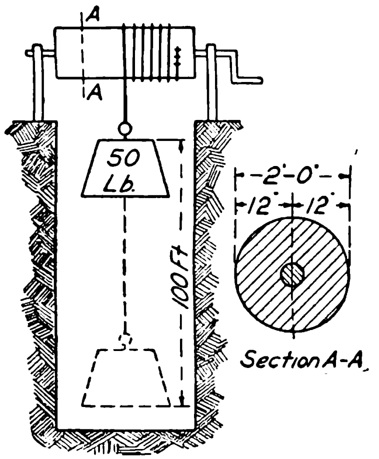


FIG. 42.—Example of work and of torque.

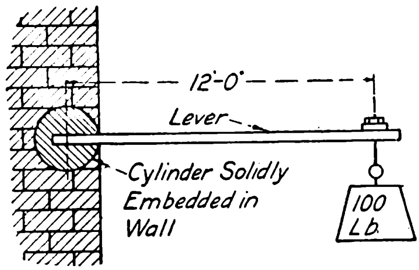


FIG. 43.—An example of torque.

89. Centigrade and Fahrenheit Thermometer Scales

Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.
0	32.	21	69.8	41	105.8	61	141.8	81	177.8
1	33.8	22	71.6	42	107.6	62	143.6	82	179.6
2	35.6	23	73.4	43	109.4	63	145.4	83	181.4
3	37.4	24	75.2	44	111.2	64	147.2	84	183.2
4	39.2	25	77.	45	113.	65	149.	85	185.
5	41.	26	78.8	46	114.8	66	150.8	86	186.8
6	42.8	27	80.6	47	116.6	67	152.6	87	188.6
7	44.6	28	82.4	48	118.4	68	154.4	88	190.4
8	46.4	29	84.2	49	120.2	69	156.2	89	192.2
9	48.2	30	86.	50	122.	70	158.	90	194.
10	50.	31	87.8	51	123.8	71	159.8	91	195.8
11	51.8	32	89.6	52	125.6	72	161.6	92	197.6
12	53.6	33	91.4	53	127.4	73	163.4	93	199.4
13	55.4	34	93.2	54	129.2	74	165.2	94	201.2
14	57.2	35	95.	55	131.	75	167.	95	203
15	59.	36	96.8	56	132.8	76	168.8	96	204.8
16	60.8	37	98.6	57	134.6	77	170.6	97	206.6
17	62.6	38	100.4	58	136.4	78	172.4	98	208.4
18	64.4	39	102.2	59	138.2	79	174.2	99	210.2
19	66.2	40	104.	60	140.	80	176.	100	212.
20	68.	......	......	......	......	......	......	......	......

For values not appearing in the table use the following formulas:

$$\text{Temp. C.} = \tfrac{5}{9} \times (\text{Temp. F.} - 32.)$$

$$\text{Temp. F.} = (\tfrac{9}{5} \times \text{Temp. C.}) + 32.$$

MEASURING, TESTING AND INSTRUMENTS

90. **Electricians often test circuits for the presence of voltage by touching the conductors with the fingers.** This method is safe where the voltage does not exceed 250 and is often very convenient for locating a blown-out fuse or for ascertaining whether or not a circuit is alive. Some men can endure the electric shock that results without discomfort whereas others cannot. Therefore, the method is not feasible in some cases. Which are the outside wires and which is the neutral wire of a 110–220 volt, three-wire system can be determined in this way by noting the intensity of the shock that results by touching different pairs of wires with the fingers. Use the method with caution and be certain that the voltage of the circuit does not exceed 250 before touching the conductors. (This and the several paragraphs that follow are taken from *Electrical Engineering*.)

91. **The presence of low voltages can be determined by "tasting."** The method is feasible only where the pressure is but a few volts and hence is used only in bell and signal work. Where the voltage is very low, the bared ends of the conductors constituting the two sides of the circuit are held a short distance apart on the tongue. If voltage is present a peculiar mildly burning sensation results which will never be forgotten after one has experienced it. The "taste" is due to the electrolytic decomposition of the liquids on the tongue which produces a salt having a taste. With relatively high voltages, possibly 4 or 5 volts, due to as many cells of battery,

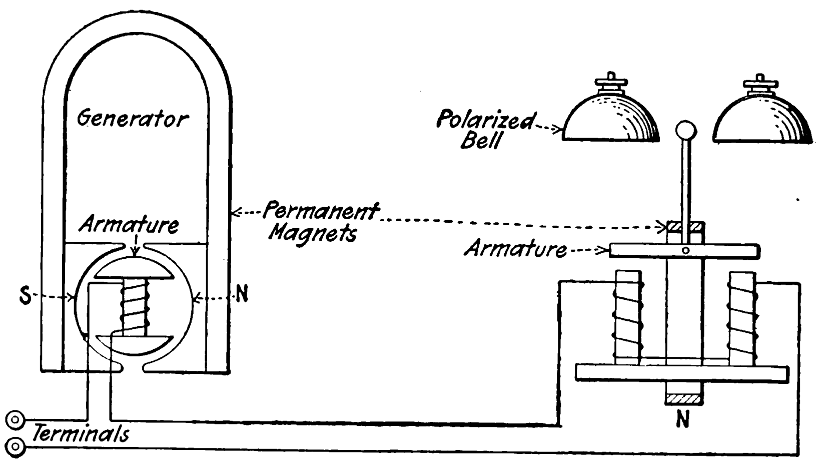


FIG. 44.—Circuits of testing magneto.

it is best to first test for the presence of voltage by holding one of the bared conductors in the hand and touching the other to the tongue. Where a terminal of the battery is grounded, often a taste can be detected by standing on moist ground and touching a conductor from the other battery terminal to the tongue. Care should be exercised to prevent the two conductor ends from touching each other at the tongue, for if they do a spark can result that may burn.

92. **The magneto test set** is one of the most valuable testing instruments to the practical man because of its simplicity and the fact that it is always ready for service. Fig. 44 shows the circuit and Fig. 45 a perspective view of a testing magneto. The apparatus consists of a small hand-operated alternating-current generator in series with a polarized electric bell. Alternating current will ring bells of this type. If the external circuit connected to the terminals of the magneto is closed and the crank of the generator is turned, current will flow and the bell will ring.

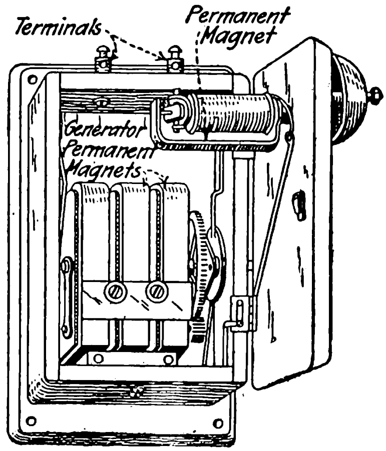


FIG. 45.—Assembly of testing magneto.

The resistance through which magnetos will ring is determined by their design. An ordinary magneto will ring through possibly 20,000 to 40,000 ohms. Electrostatic capacity effects must be considered when testing with a magneto. When testing long circuits, such as telephone lines or circuits that are carried in cable for a considerable distance, the bell of the magneto may ring, due to capacity, apparently indicating a short-circuit, whereas the circuit may be perfectly clear or open. Circuits associated with iron, such as field coils of generators, may have considerable inductance. With highly inductive circuits under test, the magneto may "ring open"; that is, the bell may not ring at all, even though the inductive circuit connected to it be actually closed. In ordinary wiring work the effects of capacity and inductance are usually negligible and the true condition of the circuit will be indicated by the performance of the magneto bell.

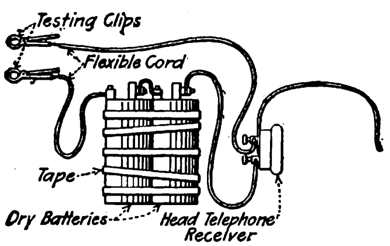


FIG. 46.—Head-telephone and dry-battery testing set.

93. **A telephone receiver in combination with one or two dry cells constitutes an excellent equipment for certain tests.** A "head" telephone receiver (Fig. 46) is usually preferable to those of the watch-case types, because it is held on the head by the metal strap, allowing the unrestricted use of both hands. Metal testing clips—suspender clips will do—are soldered to the flexible testing cords. The telephone receiver is extremely sensitive and will give a weak "click" even when the current to it passes through an exceedingly high resistance. In using, one clip is gripped on one conductor of the circuit to be tested and the other clip is tapped against the other conductor. Prolonged connection should be avoided because it will "run down" the battery. A vigorous click of the receiver indicates

a closed circuit, while a weak click or none at all, indicates an open circuit. After practice it is possible to determine approximately the resistance of the circuit under test by the intensity of the receiver click. When the battery and receiver test set are connected to a circuit having some electrostatic capacity, the receiver will give a vigorous click when the clips are first touched to the circuit terminals, even though the circuit be open. With successive touchings the click will diminish in intensity if the circuit is open, but will not diminish appreciably if the circuit is closed.

94. **The advantages of the telephone receiver over the magneto** for work of certain classes are: (1) The receiver and battery outfit costs little. (2) The outfit can be made so compact that it can be carried in the pocket. (3) In making insulation tests with a magneto the circuit may "ring clear"; that is, the bell will not ring, apparently indicating high insulation resistance, whereas the circuit may not be clear, but instead the magneto may be out of order or its local circuit open. The indication is negative. With the telephone receiver a slight click is produced even when testing through the highest resistances. The absence of a click usually signifies an open in the testing apparatus itself. Thus the telephone receiver indication is positive.

95. **A telegraph sounder is sometimes used for testing.** It is connected in the same way as the telephone receiver of Fig. 47, and is adaptable for rough work. When the circuit under test is closed and the flexible cord clips are touched to the circuit conductors, the sounder clicks. Where the circuit is open there is no click. One feature of the sounder method is that the click is audible at a considerable distance from the instrument.

96. **An electric bell outfit for testing** is shown in Fig. 47. When the free ends for testing are touched to a closed circuit of not too high resistance the bell rings. Where the circuit is open the bell will not ring. Flexible cord can be used for the testing conductors of the outfit and testing clips can be provided as in Fig. 47.

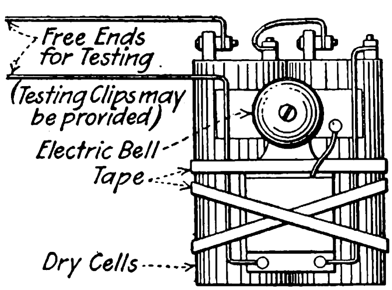


FIG. 47.—Electric bell testing outfit.

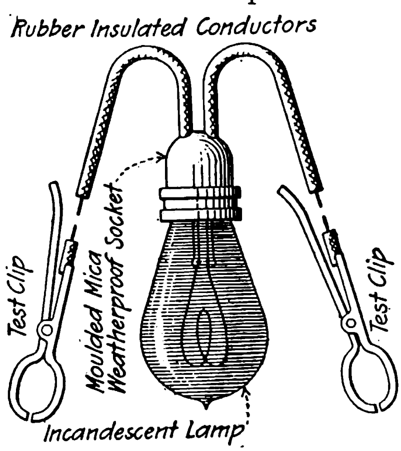


FIG. 48.—A practical test-lamp outfit.

97. **A test lamp** (Fig. 48), consisting merely of a weatherproof socket of moulded mica, into which is screwed an 8 or 16 c-p. carbon lamp of the voltage of the circuits involved, is very conve-

nient for rough tests on interior-lighting and motor-wiring systems. Porcelain sockets are undesirable because they are so readily broken. Brass sockets should not be used because they may fall across conductors and thereby cause short-circuits. Testing clips may be soldered to the ends of the leads which are moulded in the socket. Some uses of the testing lamp are given in a following paragraph, and it is very convenient for testing for defective fuses.

98. Rules for Use of Ammeter and Voltmeter (*Timbie's Elements of Electricity*).—Place ammeter in series, always using a short-circuiting switch, where possible, as shown in Fig. 49, to pre-

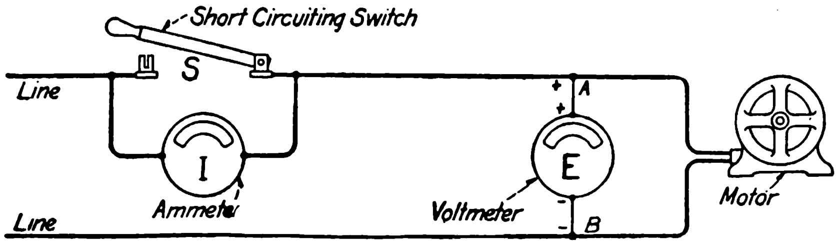


FIG. 49.—Ammeter and voltmeter connections.

vent injury to the instrument. Place voltmeter in shunt (Fig. 49). Put the + side of the instrument on the + side of the line. Fig. 49 shows the correct use of an ammeter and a voltmeter to measure the current and the voltage supplied to the motor. The short-circuiting switch *S* must be opened before the ammeter is read. All the current that enters the motor must then flow through the ammeter and be indicated. The ammeter is of very low resistance (about 0.001 or 0.002 ohm) and does not appreciably cut down the flow of current. The voltmeter is of very high resistance (about 15,000 ohms) and does not allow any appreciable current to flow

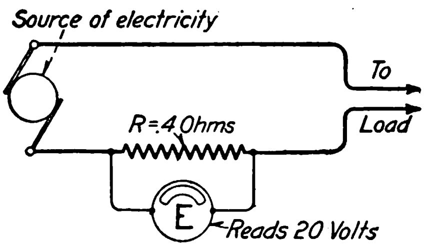


FIG. 50.—Current measurement with voltmeter.

through itself. Yet enough goes through the voltmeter to cause it to indicate the voltage across the terminal *AB* of the motor. Suppose the voltage across the motor to be 110, what would happen if an ammeter of 0.002 ohm resistance were by mistake placed across *AB*? (Remember Ohm's law is always in operation.)

99. Ohm's law is often applied in making determinations of resistance, voltage, current and power. In 35 and 36 examples are given that indicate the application of Ohm's law to measurements.

100. A method of measuring current with a voltmeter is shown in Fig. 50. If a resistor of known resistance be connected in series in a circuit and the voltage across the coil measured with a voltmeter the current can be determined by Ohm's law thus:

Example.—(Fig. 50.) If the drop around 0.4 ohm resistance in series in a circuit is 20 volts, what is the current in the circuit?

Solution.—Substitute in the Ohm's law formula:

$$I = \frac{E}{R} = \frac{20}{0.4} = 50. \text{ amp.}$$

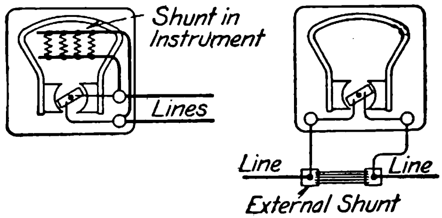


FIG. 51.—Millivoltmeters and shunts.

101. A millivoltmeter is generally used for making measurements like that of 99. A millivoltmeter reads in thousandths of volts so that a resistor of small resistance can be used. Ammeters, particularly those for large currents, are often millivoltmeters calibrated in amperes which are connected around a resistor, in series with the circuit (Fig. 51). The resistor is sometimes in the instrument case and is sometimes inserted in the bus-bars of a switchboard. See Fig. 51. Such resistors are called **shunts** and when furnished by instrument makers are carefully calibrated.

102. Resistance can be measured with a voltmeter as indicated in Fig. 52. A resistor of known resistance, a source of electricity

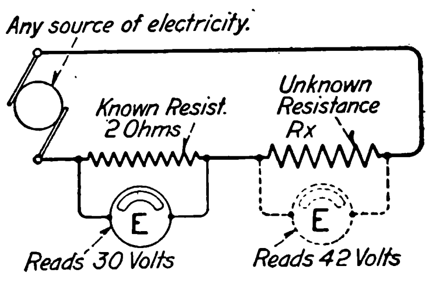


FIG. 52.—Resistance measurement.

and one voltmeter is required. The same constant current flows through both the known and the unknown resistance. The voltmeter reading E is taken and then the reading Ex. The voltage drops will be proportional to the resistances or:

$$\frac{R}{E} = \frac{R_x}{E_x} \text{or } R_x = \frac{E_x \times R}{E}$$

Example.—Substituting the values from Fig. 52 in the formula:

$$R_x = \frac{E_x \times R}{E} = \frac{42 \times 2}{30} = \frac{84}{30} = 2.8 \text{ ohms.}$$

103. Very small resistances can be measured, as indicated in Fig. 53, with an ammeter and a millivoltmeter. This method is convenient for measuring the resistance of bus-bars, joints between conductors, switch contacts, brush-contact resistance and other low resistances. As large a current as is feasible should be used. This is another application of Ohm's law.

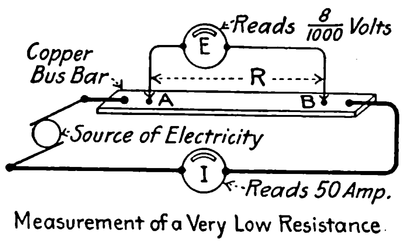


FIG. 53.—Measurement of very low resistance.

Example.—What is the resistance of the portion of the bus-bar between A and B, Fig. 53?
Solution.—Substitute in Ohm's law formula:

$$R = \frac{E}{I} = \frac{0.008}{50} = 0.00016 \text{ ohms.}$$

104. Insulation resistance is usually measured as suggested in Fig. 54. A voltmeter of known resistance, preferably of high resistance, and a source of e.m.f. (batteries or a generator), are required. First the voltage of the e.m.f. source is taken as shown

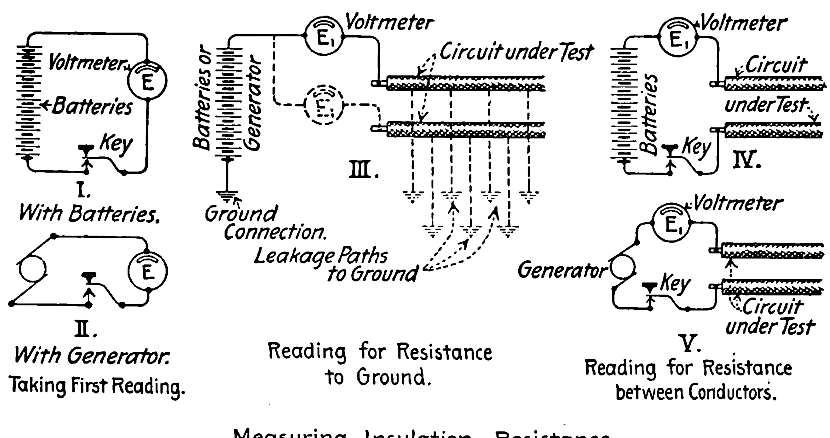


FIG. 54.—Measuring insulation resistance.

at *I* or *II*. The apparatus is then arranged as shown at *III* to measure the resistance from each side of the circuit to ground. At *IV* or *V* are shown the connections for measuring the resistance between conductors. If $E=$ voltage of e.m.f. source, $E_1=$ reading of voltmeter when connected in series with insulation resistance to be measured, $R_v=$ resistance, in ohms, of voltmeter and R_x insulation resistance sought, the following formula is used:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) \text{ (See Fig. 54.)}$$

Example.—In a certain (Fig. 55) test where a 110-volt generator was used as a source of e.m.f. and a voltmeter having a resistance of 15,000 ohms was used to read voltages, the readings indicated in Fig. 55 were obtained. What was the insulation resistance to ground of each side of the circuit and what was the insulation resistance between circuits?

Solution.—For the resistance of *conductor* 1 (see Fig. 55) substitute in the formula:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{5} - 1\right) = 15{,}000(22 - 1) = 15{,}000 \times 21$$

$= 315{,}000$ ohms = insulation resistance of conductor 1 to ground.

For the resistance of conductor 2 (see Fig. 55, *III*):

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{4} - 1\right) = 15{,}000(27.5 - 1) = 15{,}000 \times 26.5$$

$= 397{,}500$ ohms = insulation resistance of conductor 2 to ground.

For the insulation resistance between conductors:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{2} - 1\right) = 15{,}000(55 - 1) = 15{,}000 \times 54$$

$= 810{,}000$ ohms = insulation resistance between conductors 1 and 2.

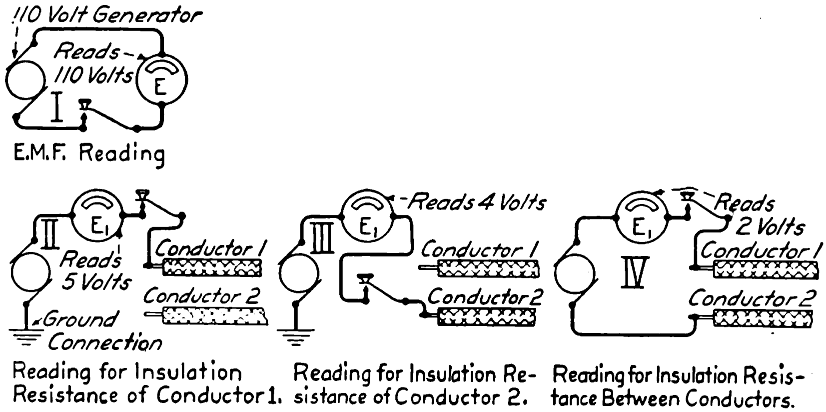


FIG. 55.—Example of insulation resistance measurement.

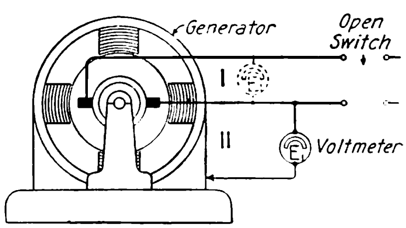


FIG. 56.—Measuring insulation resistance of a generator.

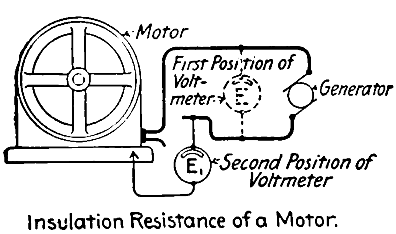


FIG. 57.—Measuring insulation resistance of a motor.

105. The insulation resistance of a generator can be determined with a voltmeter of known resistance which is successively connected and read in positions *I* and *II*, Fig. 56. The formula of **104** is used. The external circuit connected to the generator should be cut off while the measurements are being taken so that its insulation resistance will not affect the readings.

106. The insulation resistance of a motor can be measured with a voltmeter as suggested in Fig. 57. The formula of **104** is

used. Unless the external circuit has high insulation resistance its resistance will affect the result.

107. **Power,** in direct-current or non-inductive alternating-current electric circuits, **can be measured** with a voltmeter and an ammeter. For two-wire circuits the power in watts, in accordance with Ohm's law, equals the product of volts times amperes, thus:

$$P = I \times E$$

Wherein P is the power in watts, I is the current in amperes and E is the e.m.f. in volts.

Example.—See 38 for examples of power problems. Although no instruments are shown in these, the principles are the same as if instruments were used.

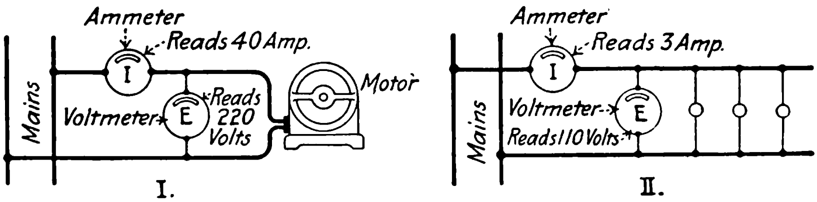


FIG. 58.—Power measurements.

Example.—In Fig. 58, *I*, the power taken by the motor is, substituting in the formula:

$$P = I \times E = 40 \times 220 = 8{,}800 \text{ watts}$$

or in kilowatts $= \dfrac{8800}{1000} = 8.8$ kw.

Example.—In Fig. 58, *II*, the power taken by the lamps is:

$$P = I \times E = 3 \times 110 = 330 \text{ watts}$$

or in kilowatts $\dfrac{330}{1000} = 0.33$ kw.

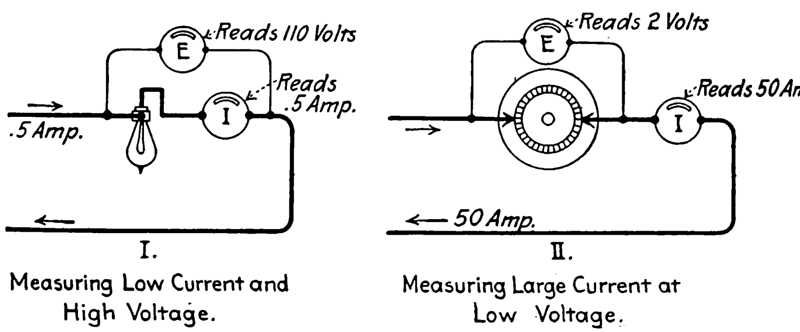


FIG. 59.—Correct methods of connecting instruments.

108. **Methods of measuring power in alternating-current circuits** are given in Pars. 59, 59A, and 148A to 151.

109. **All ammeters and voltmeters (except electrostatic) consume power when in use and introduce some error** (*Timbie's Elements of Electricity*). For minimum error (see Fig. 59, *I*) *when measuring a low current and high voltage, the voltmeter should be placed around both the ammeter and the apparatus under test.*

When measuring the power consumed by a piece of apparatus, through which a large current at low voltage is flowing, the voltmeter

should be placed immediately across the piece of apparatus under test and not across the ammeter. (Fig. 59II.)

110. The Wheatstone bridge is an instrument for measuring medium and high resistances. It is not suitable for measuring resistances of less than 1 ohm. An elementary diagram is shown in Fig. 60. R_1, R_2 and R are adjustable resistances, R_x is the unknown resistance and G is a delicate galvanometer. A battery supplies electricity. It can be shown that if, when both keys are pressed, the galvanometer shows no deflection:

$$\frac{R_1}{R} = \frac{R_2}{R_x} \quad \text{or} \quad R_x = \left(\frac{R_2}{R_1}\right) R.$$

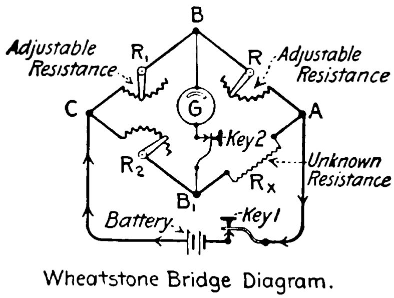


FIG. 60.—Elementary diagram of the Wheatstone bridge.

Example.—If $R_2 = 100$ ohms, $R_1 = 10$ ohms and $R = 672$ ohms what is the value of the unknown resistance?

Solution.—Substitute in the formula:

$$R_x = \left(\frac{R_2}{R_1}\right) R = \left(\frac{100}{10}\right) 672 = 10 \times 672 = 6{,}720 \text{ ohms.}$$

The unknown resistance is 6,720 ohms.

In commercial bridges, the adjustable resistances R_2 and R_1 are usually so arranged that the ratio $\frac{R_2}{R_1}$ will be a fraction like $\frac{1}{10}$ or $\frac{1}{100}$ or a number like 10 or 100 so that R_x can be obtained readily

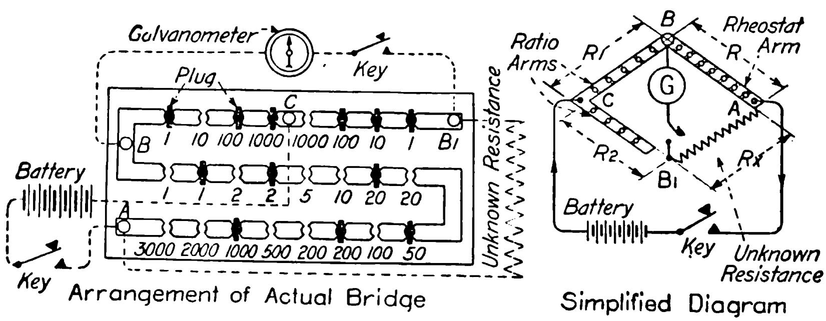


FIG. 61.—Post-office pattern of Wheatstone bridge.

by dividing or multiplying R by an easily handled number. R_1 and R_2 are sometimes called the ratio arms and R is called the rheostat arm. For most accurate results the resistances R, R_1, and R_2 should be as nearly as possible equal to R_x.

111. **A diagram of a commercial bridge of the post-office pattern** is shown in Fig. 61. Its principle is similar to that of Fig. 60. Brass plugs are used to vary the resistance in arms R, R_1 and R_2. When a plug is inserted in the opening between two resistance coils it shunts out the coil. In using this bridge the ratio $\frac{R_2}{R_1}$ is arranged by the operator to correspond to R_x. Then R is adjusted until a balance is obtained. When R_x is greater than R the ratio must be 10, 100 or 1,000, and when R_x is smaller than R the ratio must be 0.1 or 0.01 or 0.001. If $R_1 = R_2$ the value of R_x equals R.

112. **Directions for using a Wheatstone Bridge.**—(1) Insert the unknown resistance. (2) Make a mental estimation of the probable value of the unknown resistance. If it is not greater than the total resistance in the arm R or smaller than that of any one coil in R, R_1 and R_2 may be made equal by taking plugs from the proper holes. (3) Take a plug from a coil, in R, of about the

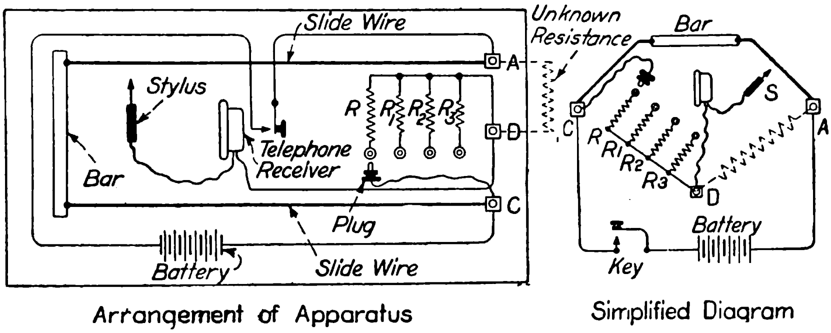


Fig. 62.—The ohmmeter.

estimated resistance of R_x and press the keys. Note the deflection of the needle, whether it is to the right or left. Now unplug a coil in R of about twice the resistance of the first one unplugged. If the needle now deflects in the opposite direction the value of R_x lies between these two values. If the deflection is in the same direction the unplugged resistance in R is too great and a value of about one-half that originally selected should be tried. Systematically narrow down the limits until the best possible balance is obtained. (4) Usually it is impossible to secure an exact balance. When this is the case proceed as indicated in the following example: Assume that the coil of smallest resistance in the R arm is of 0.1 ohm. With this added the galvanometer deflects two divisions to the right. The deflection without is three divisions to the left. Therefore a difference of 0.1 ohm makes a difference of five scale divisions. The resistance that would give no deflection is $\frac{3}{5} \times 0.1 = 0.06$ ohm. (5) Be careful not to allow the metal parts of the bridge plugs to become wet or greasy from the hands. (6) Use a twisting motion when inserting the plugs. Put them in firmly but do not use enough force to twist off the insulating handles. (7) When closing the keys, close the battery key first and in opening the keys open the galvanometer key first.

113. How to Make a Slide-wire Bridge (*J. W. Himmelsbach, Power*, June 4, 1912).—The very satisfactory apparatus described in Fig. 63 can be easily and cheaply made. The only expensive part is a direct-reading, differential millivoltmeter having the zero in the middle of the scale, which reads 75 millivolts on either side of the zero point. Mount on a piece of well-seasoned 5×18×1-in. oak four binding-posts, *A*, *B*, *C*, *D*, and two lamp sockets, *L*, *L*, as shown; *M* and *N* are two small wire brads driven in the board, leaving only ⅛ in. projecting.

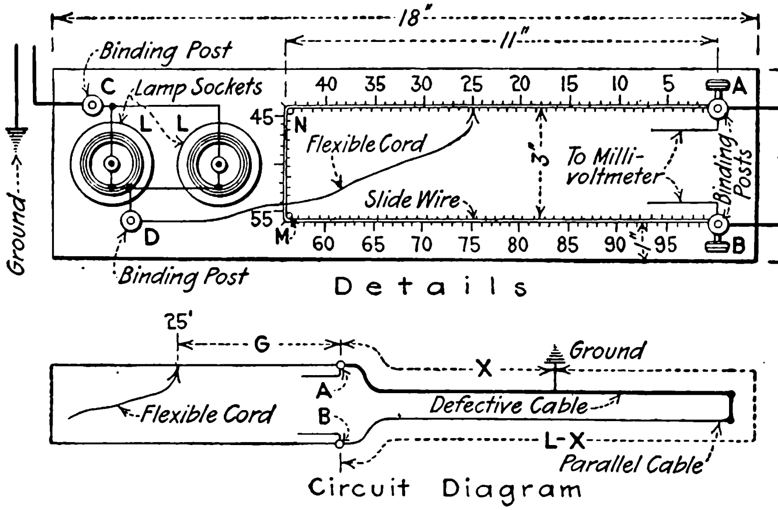


FIG. 63.—Home-made testing set and its application.

From *A* to *N*, *N* to *M*, and *M* to *B*, paste strips of paper 1 in. wide upon which a scale has been drawn, with divisions every ⅛ in., which will give 200 divisions. Mark every second division from 0 to 100, starting at *A*. Then stretch a piece of No. 26 or 28 B & S. gage, german-silver wire from *A* around *N* and *M* to *B*. This wire must be stretched tightly so that reading the scale will give correct proportional lengths of wire.

The lamp sockets are to be wired in parallel. Connect permanently to *D* a piece of flexible wire (lamp cord will do) to the end of which is soldered a knife-edge contact. This wire must reach from post *D* to post *A*. Binding posts *A* and *B* must have two connectors, as two sets of leads are fastened to them; this completes the testing set.

114. To Prepare for Testing for a Cable-ground with the Home-made Slide-wire Bridge.—Connect to the binding posts *A* and *B* respectively (Fig. 63), one lead to the available end of the grounded conductor and one lead to a conductor parallel to the grounded conductor and having the same destination. The ends of these two conductors, away from the testing set, must be joined together. Connect the millivoltmeter to the posts *A* and *B*.

If a 125-volt, direct-current circuit is available, connect one side to post *C* and ground the other, and place two 16 c-p. lamps in the

sockets. If no direct-current circuit is available, five or six battery cells connected in series can be used. Connect one terminal to C and ground the other; short-circuit the lamp sockets with a plug fuse.

115. To locate the grounded point in a cable with the home-made slide-wire bridge, run the knife-edge contact connected to D (Fig. 63) along the graduated wire until the millivoltmeter reads zero. Suppose the reading on the wire is 25 divisions from A. Referring to the lower diagram, if the total length of the cable loop is L, and the distance from the station to the ground is X, then the following proportion holds good:

$$25 : X = 75 : L - X$$

solving for X,

$$75X = 25L - 25X$$
$$100X = 25L$$
$$X = 0.25L$$

and if the length of the cable is known, the distance X can readily be determined.

Designating the distance from A to the point on the slide wire which gives zero deflection on the millivoltmeter as G, and the distance from B around to this point as H, also the total loop length of the conductor, and the distance from the station to the ground, L and X, respectively, as before, then:

$$G : X = H : L - X$$
$$GL - GX = HX \qquad (1)$$

but G plus H equals 100; therefore,

$$H = 100 - G \qquad (2)$$

substituting (2) in (1),

$$GL - GX = 100X - GX$$
$$100X = GL$$
$$X = \frac{G \times L}{100}$$

which is the formula to be used when locating grounds with this apparatus.

If the ground is due to water—which will mean that it is not confined to one point—this method is not very satisfactory. If two or three conductors in the faulty cable are grounded, thus making it impossible to get a cable clear from ground for a return, it will, in all probability, be unnecessary to make the location test as a double ground is equivalent to a short-circuit, and short-circuits are usually very apparent.

116. The ohmmeter is a special form of slide-wire Wheatstone bridge. There are several types. One is shown in Fig. 62. The slide wire connected through a bar of practically zero resistance forms two arms of the bridge. A known resistance R, R_1, R_2, or R_3, forms the third arm and the unknown resistance forms the fourth arm. Instead of a galvanometer a telephone receiver is used. It is connected to a metal-pointed stylus which can be touched at any point along the slide wire. The battery key is on the telephone receiver. At the point where tapping the

slide wire with the stylus produces no sound in the receiver the unknown resistance is indicated directly in ohms on a scale under the slide wire.

Several scales indicating ohms can be provided under the slide wire and each scale may be printed in a different color. The holes of R, R_1, R_2, and R_3 are marked each with the color corresponding to the scale that is to be used when the plug is in the corresponding hole. A battery is used in some ohmmeters and an induction coil or a magneto in others.

117. To use the ohmmeter of Fig. 62, connect the unknown resistance as shown. Close the key. Pass the stylus along the wire gently tapping it and hold the telephone receiver to the ear. The unknown resistance will be indicated on the scale at the point where tapping produces no sound in the receiver. The plug P must be in some one of the resistance holes while the test is being made. Read from the scale of the color corresponding to the color at the hole in which P is inserted.

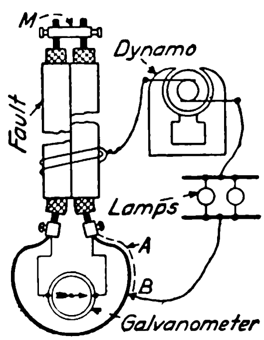


FIG. 64.—Locating a fault in a cable.

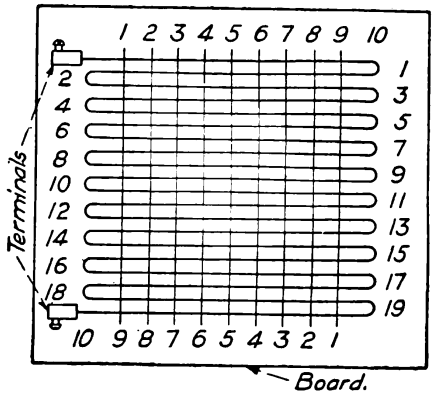


FIG. 65.—Home-made wire bridge.

118. Locating Faults in a Cable (*Standard Underground Cable Co.*).—Fig. 64 shows a simple method, using a dynamo, a galvanometer, and 10 or 15 ft. of bare wire. This method is only applicable when both conductors of the cable are of the same size. After making the connections shown it is only necessary to move the stylus b along the bare wire until the galvanometer is not deflected in either direction.

Let A = the length of the wire between the balance point B and the faulty conductor, C = the total length of the wire, and L = the total length of the cable circuit, = twice the length of the cable.

Then distance to the fault = $\dfrac{A \times L}{C}$.

Fig. 65 shows a simple form of wire bridge which can be used for tests of this kind. The length A can be read directly and the value of C is 200. If a galvanometer is not available a telephone receiver can be used in its place. While the use of alternating

currents may introduce errors due to self induction and capacity, such errors will not generally be sufficiently great to interfere with practical results.

119. Testing Cables For Insulation with a Telephone Receiver and Battery (*Standard Underground Cable Co.*).—An extremely simple way to determine whether or not the insulation resistance of any particular wire is high or not, is as follows: A telephone receiver and battery are connected as shown in Fig. 66. One side of the battery is attached to the lead sheath of the cable or to ground, and the other side to a telephone receiver. A rubber insulated wire is attached to the other side of the telephone. To test, press the telephone receiver to the ear, and touch the wire *L* to the conductor *E*; a click will always be heard the first time. After keeping both wires in contact for several seconds, break and make the connection once more; if no sound is heard at the instant of reconnection the wire is not faulty. With intervals of time between break and make of one second with a battery of 1 volt it can be assumed that no click indicates at least a resistance of 50 megohms. When more battery is used this number is increased about in proportion to the number of cells. Care must be taken that sounds in the telephone due to induction are not misconstrued for those produced by leaks.

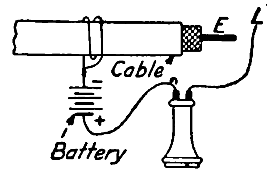


Fig. 66.—Test for insulation resistance.

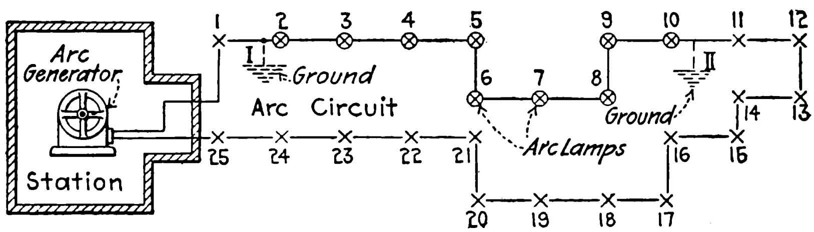


Fig. 67.—Effect of two grounds on an arc circuit.

120. Grounds on series arc or incandescent lighting circuits frequently reveal their locations automatically. If there are two good grounds on the circuit the lamps connected in the line between the grounds will not burn because the grounds will shunt them out. For example, in Fig. 67 with a good ground at *I* and *II*, the lamps Nos. 2 to 10 would be shunted out. Sometimes there may be two grounds on a circuit, but they may not be "good" enough to shunt out the lamps. (This paragraph and those that follow on testing arc circuits are from *Electrical World*.)

The presence of but one ground on a circuit, irrespective of how "good" it is, will not reveal itself automatically and the proper operation of the circuit will not be affected by one ground. However, where there is one ground, it constitutes a serious menace to the lives of the station operators and trouble-men. Furthermore, another ground may occur at any time that may cause the

shunting out of lamps or possibly a fire or destruction of equipment. Hence, it is very desirable to maintain the circuits entirely clear of grounds. It is the practice in all well-maintained stations to test each series circuit for grounds, some time during every afternoon, and if a ground is discovered a trouble-man is sent out to locate and clear it before the circuit is thrown into service for the night.

121. **The usual method of testing dead series circuits for grounds** is to disconnect the circuit from all station apparatus and then to connect one terminal of a magneto test set to the circuit and the other to ground. If the bell rings vigorously when the crank is turned, the circuit is grounded. If it does not, the circuit is clear. If the circuit is very long or in cable for a considerable portion of its length, the bell may ring some even if the circuit be clear of grounds.

122. **The method of locating a ground on a dead arc circuit** is illustrated in Fig. 68. Disconnect all station apparatus and temporarily ground one side of the circuit as at *B* (Fig. 68). Proceed out along the line and connect some testing instrument (a

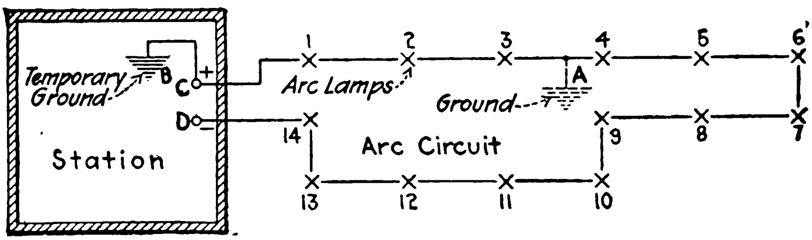


FIG. 68.—Locating a ground on a dead arc circuit.

magneto test set is most frequently used) in series with the circuit at some point. If when the crank is turned the magneto bell rings, indicating a closed circuit, the tester is between the station ground and the ground on the circuit. If the magneto "rings open," the tester is between the circuit ground and the ungrounded station end of the circuit. If in Fig. 68 the test is inserted at lamps 1, 2 or 3, the magneto should ring "closed," while if inserted at any of the other lamps it should ring "open."

123. **In locating either a ground or an open on a series circuit,** unless the tester has an idea as to the location of the trouble, he should proceed first to the middle point of the circuit and there make his first test. This first test will indicate on which side of the middle point the trouble is. He should then proceed to the middle point of the half of the circuit that shows trouble and there make another test. This will localize the trouble to one quarter of the circuit. This "halving" of the sections of the circuit should be continued until the trouble is finally found.

If there is more than one ground on a series circuit the trouble is tedious to locate. If the tests made at different points on the circuit are confusing, indicating the existence of several grounds, the best procedure is to open the circuit into several distinct sections and then test each one as a unit, following the methods described in preceding paragraphs.

124. A ground on a series circuit can sometimes be located with the current from the arc generator or rectifier by placing a temporary ground on the circuit at the station. For example, if in Fig. 68 a temporary ground is connected to terminal *B* and the device that supplies the operating current to the circuit is connected to terminals *C* and *D* and normal operating current thrown out on the circuit, the lamps 1, 2, and 3 will not burn, indicating that the ground is between lamps 3 and 4. The use of this method is attended by some fire risk; hence, the method should be used with caution.

125. A method of locating a ground on a series circuit with a lamp bank is suggested in Fig. 69. A bank of 110-volt incandescent lamps, each of the same candle-power, is connected in series as

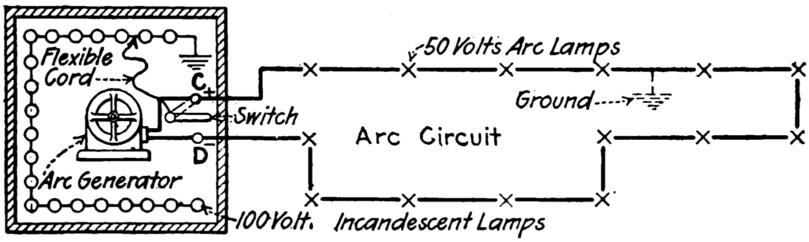


FIG. 69.—Locating a ground on a "live" arc circuit with an incandescent lamp bank.

indicated and one end of the bank is permanently grounded. There should be a sufficient number of lamps in the bank so that the sum of the voltages of all of the lamps is at least equal to the voltage impressed on the series circuit by the arc generator or the regulator. For instance, if the voltage impressed on the series circuit is 6,600, there should be at least sixty 110-volt incandescent lamps in the bank ($6{,}600 \div 110 = 60$).

In locating a ground, the flexible cord which is connected to the center point of the double-throw switch is successively placed on different points on the conductor that connects the incandescent lamps in series, the switch being thrown to one or the other of the circuit terminals, *C* or *D*. Move the flexible cord along until the incandescent lamps in the bank, between the point of connection of the cord and the permanent ground, burn at about full brilliancy. When this condition obtains, the voltage impressed across the lamps that are burning fully brilliant is approximately equal to the voltage impressed on the portion of the arc circuit (to which the switch connects) between the station and the ground. The voltage required across each lamp of the outside circuit being known, the number of lamps between the station and the ground can be readily computed, and thereby the ground is located.

Great care must be exercised in using this method. Practically all series lighting circuits operate at very high voltage. Hence, when the flexible cord is being moved along the conductor, the arc generator or regulator should be entirely disconnected. If it is not some one may be killed.

Example.—Consider Fig. 69. There is a ground on the circuit. It is found that two of the incandescent lamps of the bank burn at full brilliancy between the flexible-cord connector and the lamp-bank ground. Since 110-volt lamps are used in the bank the voltage across these two is 220. This means that the voltage on the arc circuit between points *C* and *G* is about 220. Since the arc lamps each require about 50 volts there must be $220 \div 50 = 4.4$, or in round numbers 4, arc lamps between *C* and the ground *G*. After making a test with the switch point on *C*, it should be thrown over to *D*, and a check test made from the other end of the circuit. The method of figuring is the same in each case.

126. **To locate an "open" on a series circuit** ground one end of the circuit at the station as in Fig. 68. Then make tests at different points out on the circuit with the magneto connected in between line and ground. So long as the magneto bell indicates a closed circuit, the open is on the line side of the tester. When the magneto indicates an open circuit the open is toward the station from the tester.

127. **The testing out of a concealed wiring system for proper connections** is illustrated in Fig. 70. It is assumed that the wires are installed and that the locations of their runs are concealed

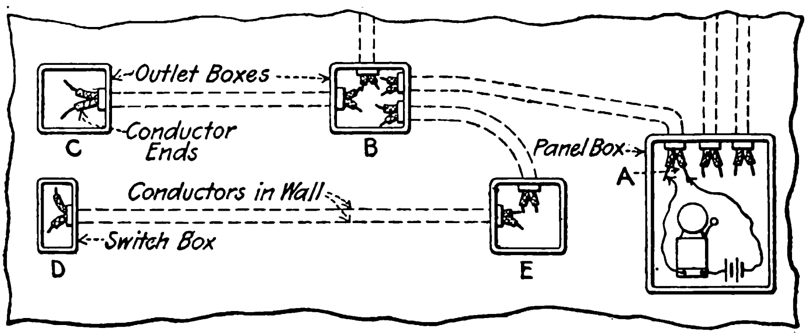


FIG. 70.—Testing out wiring for proper connections.

by the plastering. Only the ends of the conductors are visible at the outlets. It is necessary to identify the conductor ends at each outlet. These tests are usually made with an electric-bell outfit (Fig. 47) because the sound of the bell will indicate a closed circuit to the wireman in a distant room. Hence, a single man can test out such a system. In testing out, first skin the ends of all of the conductors and see that none is in contact with any other or with the outlet box. Next, select a pair of conductors (Fig. 70*A*), preferably the pair that serves the group, and connect the bell outfit to the ends of the pair as shown. Then proceed to the outlet (Fig. 70*B*) at which the pair of conductors should terminate and successively touch together the ends of all the wires that terminate in that box until a pair is discovered that, touching together the ends of which, rings the bell. This identifies one pair. Tag this pair so that it can be readily found again and repeat the process on some other pair. Continue this until all of the conductors are identified. (This paragraph and those that follow on practical electrical tests from *Electrical Engineering.*)

128. **The method of testing out the connections for three-way**

switches is shown in Fig. 71. When finally connected the circuits should be as shown at *I*. It is assumed that the conductors are in place and concealed within walls or ceilings and that only the ends are visible at the outlets, as at Fig. 71, *II*. First, identify the feed conductors and bend back their ends at the outlet box as at A_3. Next, twist together, temporarily, the bared ends of any two of the conductors at each of the switch outlets as at A_3 and C_3. The conductors having their ends thus twisted together will be the switch conductors. Now, at the lamp outlet, or outlets, identify the short-circuited switch conductors as directed in a

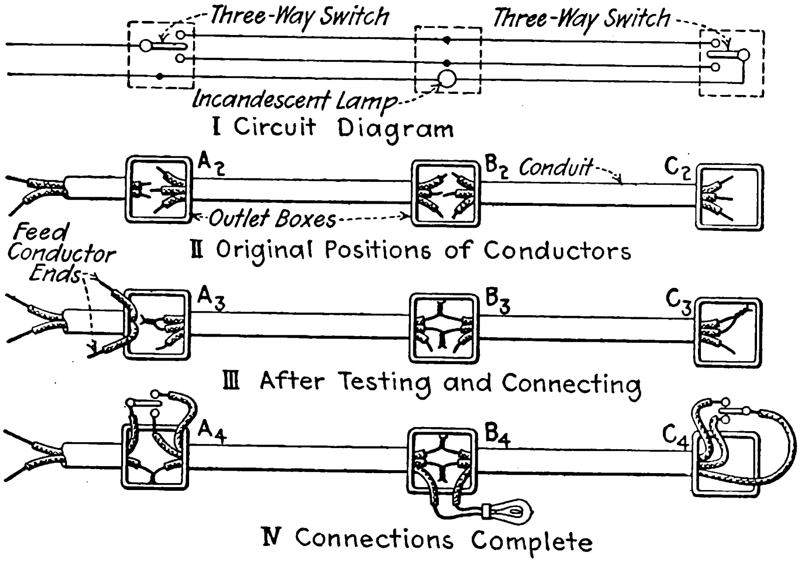


FIG. 71.—Testing out three-way switch connections.

preceding paragraph and connect and solder these switch conductors together as at B_3. Connect the remaining conductor ends at the lamp outlets to the lamps, B_4, connect one of the feed conductors to the center point of the three-way switch (A_4), and connect the other feed conductor to the lamp wire. The switch conductors are connected to the two points of the switch. At C_4 the same procedure is followed.

129. In testing out a new wiring installation for faults each branch circuit, main and feeder should be treated individually. It is usually impracticable to test an installation as a unit, as open switches and loose connections in cut-outs may render such a test worthless. If a test is made from the cut-out, on the two conductors of each individual circuit, the above-mentioned possible elements of uncertainty are eliminated. Test each side of each circuit separately unless the lamps are in position.

130. Open circuits in multiple wiring installations are usually readily located. If the lamps are in position and lighting voltage available, it can be impressed on the circuit. The lamps on the generator side of the "open" will then burn while those on the far side will not, which localize the "open." Where lighting voltage is

not available, all of the lamps can be taken out of the sockets and each of the sides of the circuit can be grounded at the cut-out. Then a telephone-and-battery, a bell-and-battery, or a magneto test set can be connected temporarily and successively between one line and ground and between the other line and ground at each outlet on the branch. When the test set indicates an open circuit, the "open" is between the tester and the ground made at the cut-out.

131. **The test for short-circuits on a multiple system** is made by temporarily connecting a test set across the terminals of each branch and circuit at the cut-out. If there is a short-circuit on the lines under test, its presence will be immediately evident.

132. **The test for continuity of multiple wiring circuits** is made by temporarily connecting a test set across the terminals of each branch cut-out and successively short-circuiting, one at a time, the sockets of the branch with a screw-driver, a nail, or other metal object. The test set will then indicate whether the wiring of the circuit is open or closed. Where lighting voltage is available and plug cut-outs are used, a lamp can be screwed into one socket of the cut-out and a plug-fuse into the other. Then the tester can proceed from socket to socket and short-circuit each. Where circuit to the socket is continuous the lamp will light when the socket is short-circuited.

133. **The test for grounds on a multiple wiring installation** is made by temporarily connecting between line and ground a test set of one of the types hereinbefore described. If the test set indicates a short-circuit, the line being tested is grounded.

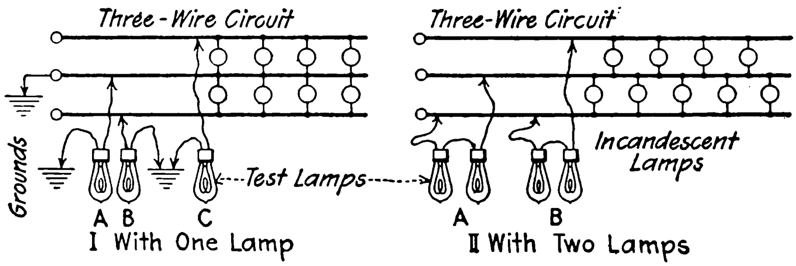


FIG. 72.—Locating neutral wire with test lamp.

134. **The testing of three-wire circuits to identify the neutral,** is effected as suggested in Fig. 72. Where the neutral is grounded, a test lamp can be successively connected between each of the three conductors and ground (Fig. 72, *I*). When the ungrounded side of the lamp is touched to the neutral wire it will not burn, but when touched to either of the outside wires it will burn. A method that can be used with either a grounded or an ungrounded neutral is illustrated in Fig. 72, *II*. Connect the two test lamps in series successively between one of the line wires and the other two. When connected across the two outer wires both lamps will burn at full voltage, but when connected between one of the outer wires and neutral they will burn at only half voltage. The "touching" test described in a previous paragraph (**90**) can also be applied.

135. Polarity of direct-current circuits can be determined by holding the two conductors in a glass vessel of water as indicated in Fig. 73. It may be necessary to pour a little common salt or

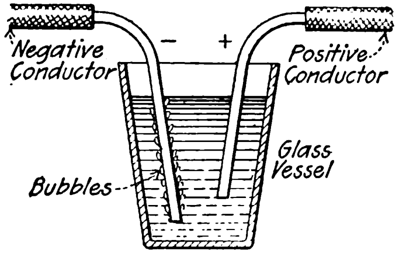


FIG. 73.—Determination of polarity with conductor ends in water.

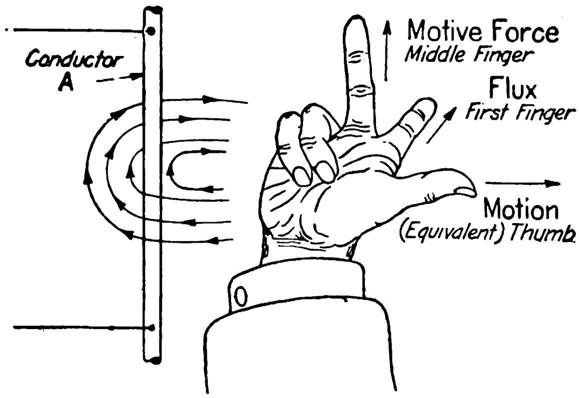


FIG. 74.—Application of right-hand rule.

acid into the water to render it conducting. Pure water is a poor conductor. Bubbles will form only on the negative conductor, indicating the presence of current and the polarity of the circuit. Be careful not to touch the conductor ends together which will cause a short-circuit.

136. A Hand Rule to Determine the Direction of an Induced e.m.f.—(See Fig. 74.) Use the *right hand.* Extend the thumb in the direction of the motion, or of the equivalent motion, of the conductor and the forefinger in the direction of the magnetic flux. Then the middle finger will point in the direction of the induced e.m.f. (Magnetic flux flows from the north (N) to the south (S) pole of a magnet.) This rule can be remembered by associating the sounds of the following word groups: "thumb—motion," "forefinger—force" and "middle finger—motive force."

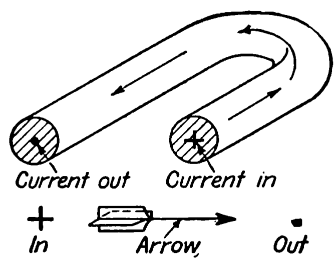


FIG. 75.—Symbols indicating direction of current flow.

137. Symbols for indicating the direction of an e.m.f. or current into or out of the end of a conductor are shown in Fig. 75.

138. Hand Rule for Direction of Magnetic Field about a Straight Wire.—(See Fig. 76.) If a wire, through which electricity is flowing, is so grasped with the *right hand* that the thumb points in the direction of electricity flow, the fingers will point in the direction of the magnetic field and vice versa.

139. Hand Rule for Polarity of a Solenoid or Electromagnet.—(See Fig. 77.) If a solenoid or an electromagnet be so grasped

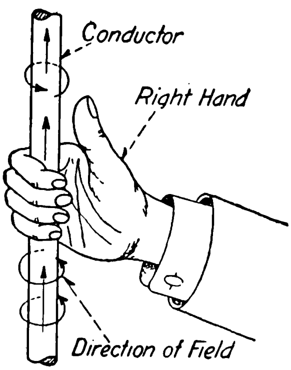


FIG. 76.—Hand rule for direction of field.

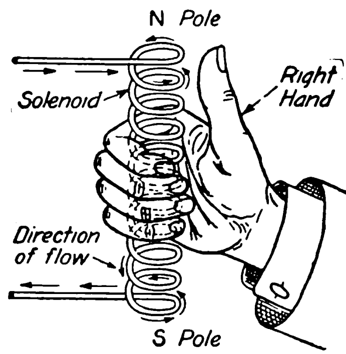


FIG. 77.—Hand rule for determining polarity of a solenoid.

with the *right hand* that the fingers point in the direction of electricity flow, the thumb will point toward the north (—) pole.

140. Rule for Determining Direction of Current Flow with a Compass.—(See Fig. 78.) If a compass is placed under a conductor, in which electricity is flowing from south to north, the north end of the needle will be deflected to the west. If the compass is placed over the conductor, the north end of the conductor will be deflected to the east. If the direction of current flow in the conductor is reversed the direction of deflection of the needle will be reversed correspondingly.

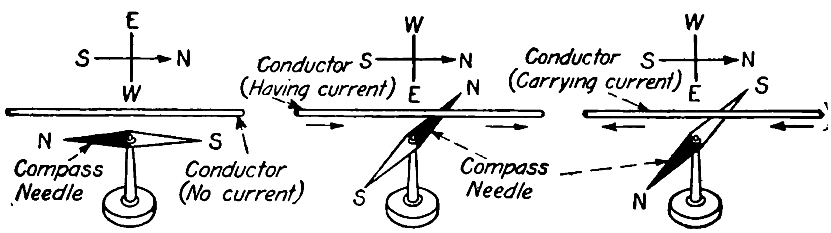


FIG. 78.—Performance of a compass needle near a conductor.

141. Ground Detectors.—(*Factory Mutual Insurance Co's. Book of Rules.*) The purpose of the ground detector is to give a warning when the first break in insulation occurs, thereby giving time to repair it before the second one, with its possible accompanying fire, can follow. The instant a detector shows a ground, steps should be taken to find and remedy it. By throwing off one circuit after another, the one on which the ground exists will soon

be found, as when it is cut off the detector lamps will again burn with equal brilliancy. Inspection along this circuit will then generally soon disclose the trouble. Where the circuits are not well sub-divided by switches, fuses may be removed to accomplish the same result.

142. **Ground Detectors for Two-wire Direct-current Circuits.**—Fig. 79 shows a very good and simple detector for any two-wire low-voltage system. The lamps for the detector should each be of the same candle-power and voltage—the voltage being about the same as that of the regular lamps in the plant—and two lamps should be selected which, when connected in series, burn with equal brilliancy. Although somewhat greater sensitiveness can be obtained with low candle-power lamps, such as 8 c-p., for example, it is believed in general to be preferable to use lamps of same candle-power as those throughout the plant, as then a burned-out or broken detector lamp can be immediately replaced by a good lamp from the regular stock, thus avoiding the necessity of keeping on hand a few spare special lamps.

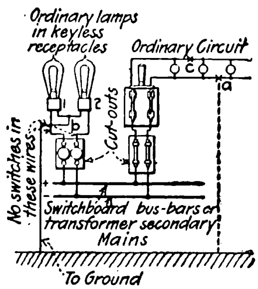


Fig. 79.—Two-lamp ground detector.

The detector lamps, being two in series across the proper voltage for one lamp, burn only dimly. If, however, a ground occurs on any circuit, as at *a*, the current from the positive bus-bar through lamp No. 1 divides on reaching *b*, instead of all going through lamp No. 2, as it did when there was no ground. Part now goes down the ground wire and through the ground to *a*, as indicated by the broken line, and thence through the wires to the negative bus-bar. This reduces the resistance from *b* to the negative bus-bar, and therefore more current flows through lamp No. 1 than before, while less current flows through lamp No. 2. Lamp No. 1 consequently brightens and lamp No. 2 dims. If the ground had occurred at *c* instead of *a*, lamp No. 2 would have brightened and lamp No. 1 dimmed.

Attention is called to the following points, which are frequently neglected in this form of detector:

1. The lamp receptacles should be keyless and there should be no switches of any kind in any of the connecting wires, so that the detector will always be in operation. In order to be of the greatest value, the indications must be given instantly when a ground occurs. The observer should not have to wait until the engineer or electrician remembers to close a switch.

2. The wires should be protected by small fuses where they connect to the bus-bars. If these fuses are omitted, a short-circuit across these wires would either burn up the wires or blow the main generator fuses.

3. The lamps should be placed very close together, within 1 or 2 in. of each other if possible. The farther apart they are, the harder it is to detect any slight difference in brilliancy between them.

4. The ground wire should be carefully soldered to a pipe which is thoroughly connected to the ground, or some other equally good ground connection should be provided.

143. A lamp ground detector for a three-wire Edison system is shown in Fig. 80. In principle it is exactly the same as the two-lamp detector of Fig. 79. Its indications are as follows:

Switch on point No. 1	Ground at *a*—A bright, B and C dim. Ground at *b*—B and C bright, A dim. Ground at *c*—A bright, B and C dim.
Switch on point No. 2	Ground at *a*—A and B bright, C dim. Ground at *b*—C bright, A and B dim. Ground at *c*—C bright, A and B dim.

With the lamp switch at point No. 1, grounds at *a* and *c* give the same indication, but by throwing the switch to point No. 2, it will be at once evident whether the ground is on the positive or negative side. It is to remove the uncertainty which would otherwise exist that this switch is needed. It should have no "off" position.

The man in charge of a plant can readily familiarize himself with the indications of the detector by purposely putting a ground on the different wires and noting the indications.

If the neutral is permanently grounded, a ground detector is, of course, of no use.

144. The same degree of sensitiveness on both sides can be obtained by means of the lamp switch in Fig. 80, but for grounds on the neutral, there is never more than half the full voltage avail-

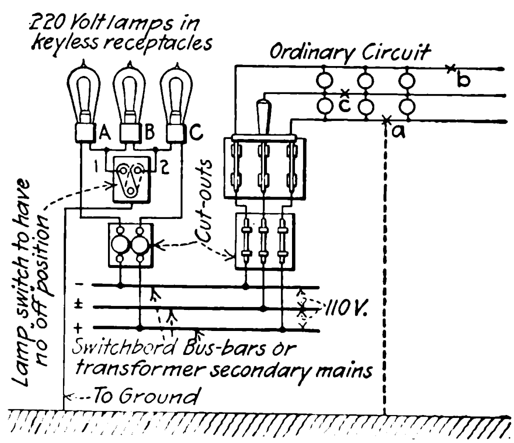


FIG. 80.—Lamp ground detector for three-wire system.

able to operate the lamps, so that the indications are necessarily less sensitive.

145. An ordinary voltmeter can be used as an intermittent ground detector on direct-current circuits of any voltage, as shown in Fig. 81. The voltmeter ordinarily used to indicate the pressure on the system can, of course, be used for this purpose, the voltmeter switch shown in the cut being arranged to give the different desired connections.

If, for example, the system shown in Fig. 81 were of about 100 volts, the voltmeter would register 100 when the levers of the switch were on the inside contact points as shown. If, now, the right-hand lever were moved to the outside contact point as shown dotted, and there were a ground on the system, as at *a*, current would pass from the positive bus-bar through the circuit to *a*, thence through the ground to the ground wire, and through the voltmeter to the negative bus-bar, causing the voltmeter to read something below 100, unless the ground at *a* were practically a perfect connection, in which case the voltmeter reading would be 100. If the positive side of the system were entirely free from grounds, the voltmeter reading would be 0.

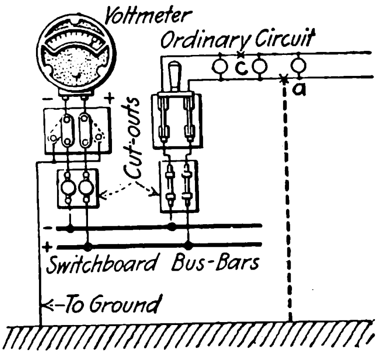


FIG. 81.—Voltmeter ground detector.

Assume that under these conditions the voltmeter reads 50, and that the resistance of the voltmeter itself was 20,000 ohms, it will be evident that if, with no external resistances, as when connected directly to the bus-bars, the voltmeter reads 100, while now it reads 50, the total resistance under the new conditions must be 40,000 ohms, of which 40,000 − 20,000 = 20,000 ohms must be the resistance of the ground at *a*.

If the voltmeter had read only 20 the total resistance would have been $\frac{100}{20} \times 20{,}000 = 100{,}000$, and the resistance of the ground 100,000 − 20,000 = 80,000 ohms.

146. Ground Detectors for Ordinary Low-voltage Three-phase Alternating-current Circuits.—A lamp detector connected as in Fig. 82 may be used. The indication is the same as that with the lamp detectors described above. Thus, when a ground comes on one wire, the lamp attached to that wire dims and the other two brighten.

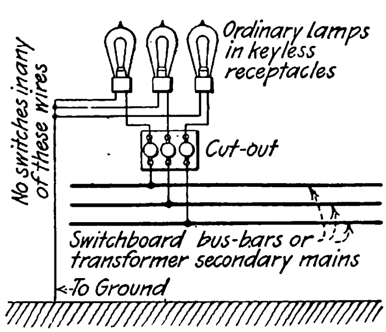


FIG. 82.—Three-phase lamp detector.

For ordinary two-phase (or quarter-phase) systems, where the phases are entirely insulated from each other, the two-lamp detector can be used, one detector on each phase. There are, however, in this class of wiring several complicated systems, to all of which the lamp detector principle is applicable, although the exact method of connections differs in each case, so that no general rule can be given.

147. The testing of lighting fixtures prior to installation is

best accomplished with a voltmeter, Fig. 83. The test for short-circuit and continuity is illustrated at *I*. If the voltmeter does not give a reading with the lamps out of the sockets, the fixture wiring is clear of short-circuits. After the test for short-circuits has been made each socket is short-circuited with a metal object —a screw-driver is frequently used—and if the voltmeter indicates the full voltage of the circuit each time a socket is short-circuited, it signifies that the circuit to that socket is continuous.

The fixture can be tested for grounds as at Fig. 83, *II*. If there is no deflection of the voltmeter with one lead from the voltmeter touching the metal work of the fixture and the other successively each of the fixture conductors, the fixture is clear of grounds. Be certain that one voltmeter terminal is in actual contact with the metal work of the fixture and not insulated therefrom by the lacquer finish. This test should be made with the lamps out of the socket.

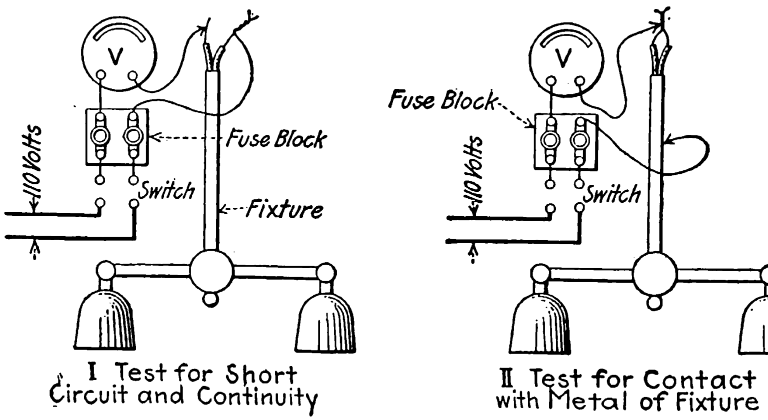


FIG. 83.—Methods of "testing out" fixtures.

148. **The measurement of the power in a single-phase circuit** is described in a preceding paragraph.

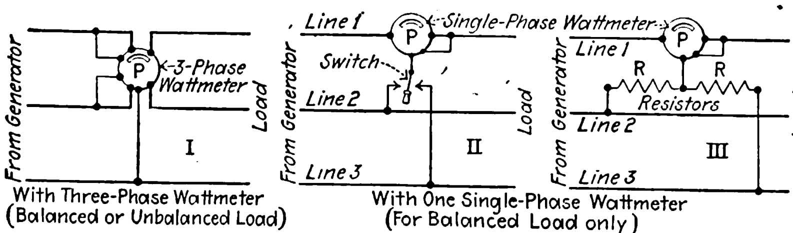
148 A. **Power in a two-phase system.** In the four-wire circuit each phase is treated as if it were a separate circuit and the total power is equal to the arithmetic sum of readings, P_1 and P_2. In the three-wire circuit the total power is equal to the algebraic sum of the wattmeter readings. That is:

$$\text{Total power} = P_1 + P_2 \text{ in watts.}$$

149. **Power in three-phase circuits can be measured with wattmeters** by several different methods. See Fig. 84. At *I* a polyphase wattmeter is shown. An instrument of this type automatically adds the portions of power consumed in each phase and indicates their sum. Instruments made by different manufacturers are arranged differently and must be connected accordingly. Directions accompany each instrument. Diagrams *II* and *III* show how the power can be measured, in a balanced circuit, with one wattmeter. One pressure lead is connected to the line in which the wattmeter is inserted and the other pressure

lead is connected successively to the other two lines. *The total power in I is equal to the sum or difference of the two readings.* If resistors are used as indicated in *III*, the power can be ascertained without any shifting of leads. The wattmeter reading of *III* multiplied by 3 will be the true power in a balanced circuit. The resistance of each of the resistors *R* and *R* must be equal to the resistance of the potential or voltage coil of the wattmeter.

With two wattmeters (as in Fig. 84, *IV*) the total power is equal to the (sum or difference) of the two wattmeter readings. If the power factor is greater than 0.50 the total power is their arithmetical sum of the readings. If it is lower than 0.50 one of the readings is negative and the power is their arithmetical difference.



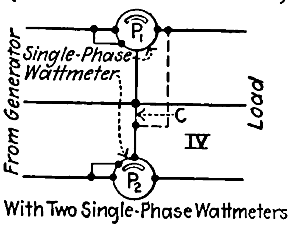


FIG. 84.—Three-phase power measurements with wattmeters.

To ascertain whether one of the wattmeters is reading negative, temporarily transfer the connection of one of the potential wires (for example *c* in *IV*, as shown by the dotted line) from the middle wire to the outside wire. If its wattmeter reverses, one of the instruments, that of the lesser indication, is reading negatively. The nature of the load usually enables one to judge roughly what the power factor is. With incandescent lamps and fully loaded motors the power factor will be high, but with under and lightly loaded motors it is likely to be low. See **151** for method of determining the **power factor** of three-phase circuits **with wattmeters.**

150. The methods of measuring the power factors of circuits are described in other paragraphs.

151. The method of determining three-phase power factor with wattmeters was well described by C. E. Howell in *Electrical World*. It is necessary to know the power factor in order to connect watt-hour meters correctly where the wiring is concealed. An abstract follows:

Fig. 85 shows the power-factor curve for two single-phase meters on a polyphase circuit. It also gives a diagram of connections and instructions as to how to use the curve. The figure should be self-explanatory. Fig. 86 gives, first, a method of checking results obtained by employing the curve given in Fig. 85 and a diagram of the connections for obtaining data for the check. The second part of Fig. 86 gives a method of determining the correct connections for two single-phase meters, or one polyphase

meter, on a three-phase circuit. If this part of Fig. 86 is employed, errors in meter connections on three-phase circuits due to the power factor being near 50 per cent. should be a minimum.

To illustrate the use of the above instructions: A 100-h.p., three-phase, 440-volt induction motor was operating on 30 per cent. full-load or 40 h.p. (29.8 kw.) at 60 per cent. power factor (afterward determined) when an order "came through" to place a polyphase watt-hour meter on the installation. Immediately after the meter had been connected the following question was asked:

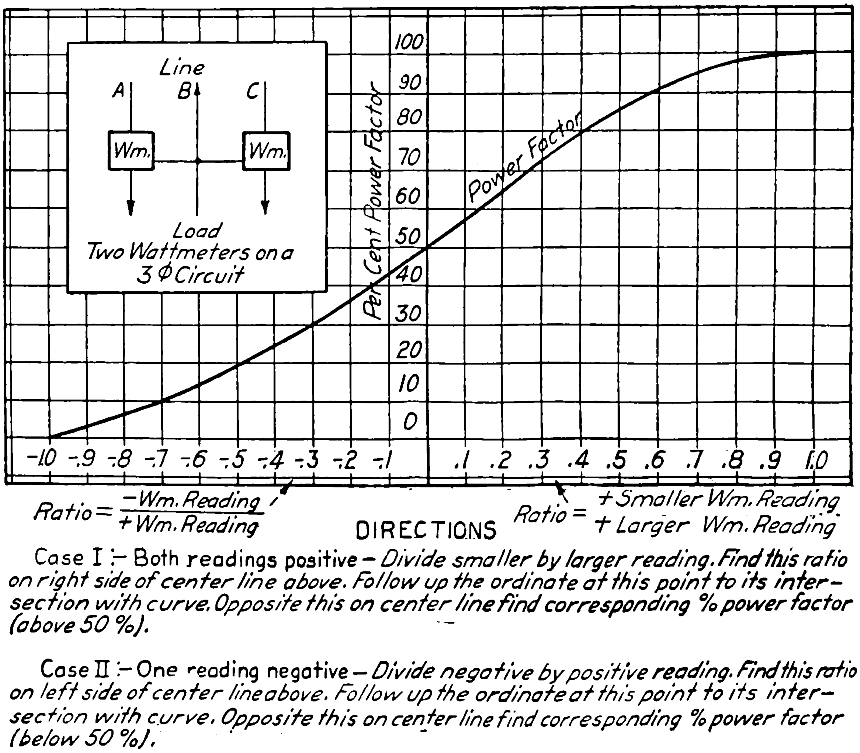


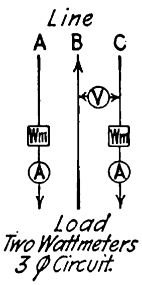
FIG. 85.—Power factor curve.

"Should the light element add to or subtract from the heavy element; that is, is the power factor above or below 50 per cent.?" As the meter leads were incased in pipe, they could not be traced, therefore the instructions in the second figure pertaining to this point were applied. The connected load of the motor having been thrown off, it was found that one element of the meter gave a negative reading. Sufficient load was then put on to bring the motor to about 80 per cent. of its full-load rating. Each element of the meter (taken separately) now read positively, but the element which on no-load gave a negative reading on 80 per cent. load read lower than the heavy element. The meter had been correctly connected when installed. Later both methods given above to determine the power factor of a three-phase circuit were

applied and both gave approximately 60 per cent. power factor (at 30 per cent. load).

152. **To correctly read the consumption indicated on the dials of a recording watt-hour meter** (sometimes, but erroneously, called a recording wattmeter) these directions should be followed: (*Rules and Regulations of the Commonwealth Edison Co., Chicago.*) See Fig. 87 for examples.

METHOD OF DETERMINING THE POWER FACTOR OF A 3-PHASE CIRCUIT.



FIRST:-Obtain the load in kilowatts from the two Wattmeters by adding (algebraicly) the reading of ϕ "A" Wm. to that of ϕ "C" Wm.

SECOND:-Obtain the 3-Phase Current of the Circuit by adding (directly) the reading of the Ammeter in ϕ "A" to that of the Ammeter in ϕ "C," and multiplying the sum by .866.

THIRD:-Calculate the apparent Load by multiplying the above "3-Phase Current in amperes" by the Voltage between Phases and dividing by 1000.

FOURTH:-Determine the Power Factor (in %) by dividing the True Load (K.W.) by the Apparent Load (Kva.) and multiplying by 100.

Power Factor Above or Below 50%

If Induction Motor load, throw off all load and run motors "light." The Power Factor will be below 50% and one Wattmeter, or Element of a polyphase meter, should read negatively. Now load up circuit to within 20% of Total Capacity. The Single-Phase Wattmeter, or Elements, which read negatively on light load should now read positively but not as high as meter, or Element, which gave a positive reading on light load. If the Meters, or Elements, are connected properly, they should fulfill the above conditions.

Note.—This is based on the fact that on "no-load" the Power Factor of an Induction Motor is below 50%.

Fig. 86.—Chart of instructions for power factor test.

The pointer on the right-hand dial of a five-dial meter registers $\frac{1}{10}$ (one-tenth) of a kilowatt-hour or 100 watt-hours for each division of the dial. A complete revolution of the hand of this dial will move the hand of the second dial one division and register 1 (one) kw-hr. or 1,000 watt-hr. A complete revolution of the hand of the second dial will move the third hand 1 (one) division and register 10 kw-hr. or 10,000 watt-hr. and so on.

Accordingly, read the hands from left to right and add 2 (two) ciphers to the reading of the lowest dial to obtain the reading of the meter in watt-hours. Where there are 4 dials on the meter, the pointer on the right-hand dial registers 1 kw-hr. or 1,000 watt-hr. for each division of the dial, and it is necessary to add 3 (three) ciphers to the reading of the lowest dial to obtain the reading in watt-hours, or the meter reads directly in kilowatt-hours.

Hands should always be read as indicating the figure which they have last passed, and not the one to which they are nearest.

Thus, if a hand is very close to a figure, whether it has passed this figure or not must be determined from the next lower dial. If the hand of the lower dial has just completed a revolution, the hand of the higher dial has passed the figure, but if the hand of the lower dial has not completed a revolution, the hand of the higher dial has not yet reached the figure, even though it may appear to have done so.

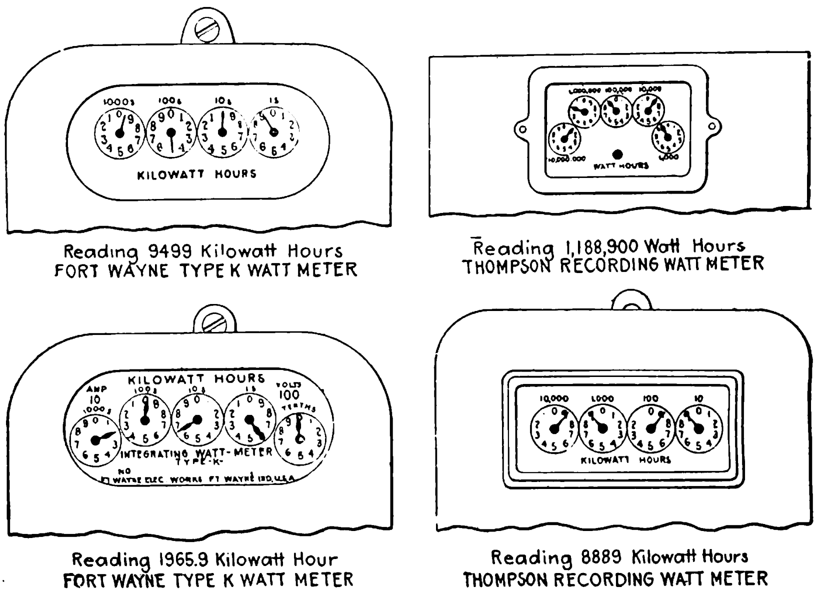


FIG. 87.—Examples of watthour meter readings.

When 1 (one) pointer is on 9 (nine), special care must be taken that the pointer on the next higher dial is not read too high, as it will appear to have reached the next number, but will not have done so until the hand at 9 (nine) has come to zero.

The hands on adjacent dials revolve in opposite directions. Therefore a reading should always be checked after being written down, as it is easy to mistake the direction of the rotation.

To determine the consumption for a given time, subtract the reading at the beginning of the period from the reading at the end. Always observe if a constant is marked at the bottom of the dial plate. If so, the difference of the readings must be multiplied by this constant to obtain the consumption.

153. Test to Determine the Horse-power of an Electric Motor.—Applying the principles, outlined elsewhere in this section, to a motor under test for output, the power delivered being measured with a prony brake, Fig. 88, may be taken as an example.

Example.—The torque is 10 lb. at 3 ft. radius, or 30 lb-ft., or 30 lb. at 1 ft. radius. Since the motor pulley is turning at the rate of 1000 r.p.m. a point on its circumference travels $2\pi rR = 2 \times 3.14 \times 1 \times 1000 = 6{,}280$ ft. per minute. At its circumference the pulley is overcoming a resistance of 30 lb. Therefore it is doing work at the rate of $30 \times 6{,}280 = 188{,}490$ ft-lb. per minute. Since, when work is done at the rate of 33,000 ft-lb. per minute, a horse-

power is developed, the motor is delivering 188,490 ÷ 33,000 = 5.7 h.p. It should be noted that, though the torque at the circumference of the motor pulley was considered in the example, it is not necessary to take the torque at that point. The torque may be taken at any point if the radius to that

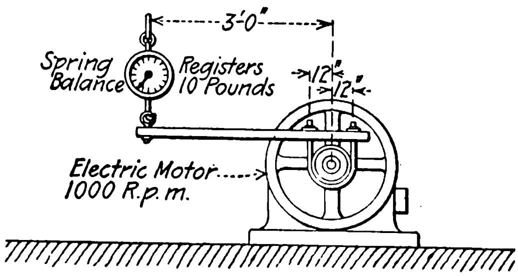


Fig. 88.—Horse-power determination with a prony brake.

point is used instead of the radius of the pulley. The formula for determining the horse-power output of a motor under test with a prony brake is

$$\text{h.p.} = 2 \times \pi TS \div 33{,}000,$$

where $\pi = 3.1416$, T = torque in pounds-feet and S is the speed of the motor in revolutions per minute. Substituting the values from the above example in this formula:

$$\text{h.p.} = 2 \times 3.14 \times 30 \times 1{,}000 \div 33{,}000 = 5.7 \text{ h.p.}$$

This is the same result secured by the former and longer method. In metric units, work is expressed in kilogram-meters, so, conversely, torque should be expressed in meter-kilograms or in kilograms at a given radius in meters.

154. **The testing of motors and generators for faults** is treated in the section on motors and generators which occupies an independent portion of this book.

PROPERTIES AND SPLICING OF CONDUCTORS

155. **Electric Wire and Cable Terminology.**—(*U. S. Bureau of Standards Publication No.* 37.)

Wire.—A slender rod or filament of drawn metal. (The definition restricts the term to what would ordinarily be understood by the term "solid wire." In the definition, the word "slender" is used in the sense that the length is great in comparison with the diameter. If a wire is covered with insulation, it is properly called an insulated wire; while primarily the term "wire" refers to the metal, nevertheless when the context shows that the wire is insulated the term "wire" will be understood to include the insulation.)

Conductor.—A wire or combination of wires not insulated from one another, suitable for carrying a single electric current. (The term "conductor" is not to include a combination of conductors insulated from one another, which would be suitable for carrying several different electric currents. Rolled conductors, such as bus-bars, are, of course, conductors, but are not considered under the terminology here given.)

Stranded Conductor.—A conductor composed of a group of wires or any combination of groups of wires. (The wires in a stranded conductor are usually twisted or braided together.)

Cable.—(1) A stranded conductor (single-conductor cable); or (2) a combination of conductors insulated from one another (multiple-conductor cable).

The component conductors of the second kind of cable may be either solid or stranded, and this kind of cable may or may not have a common insulating covering. The first kind of cable is a single conductor, while the second kind is a group of several *conductors.* The term "cable" is applied by some manufacturers to a solid wire heavily insulated and lead covered; this usage arises from the manner of the insulation, but such a conductor is not included under this definition of "cable." The term "cable" is a general one and in practice it is usually applied only to the larger sizes. A small cable is called a "stranded wire" or a "cord," both of which are defined below. Cables may be bare or insulated, and the latter may be armored with lead or with steel wires or bands.

Strand.—One of the wires or groups of wires of any stranded conductor.

Stranded Wire.—A group of small wires, used as a single wire. (A wire has been defined as a slender rod or filament of drawn metal. If such a filament is subdivided into several smaller filaments or strands, and is used as a single wire, it is called "stranded wire." There is no sharp dividing line of size between a "stranded wire" and a "cable." If used as a wire, for example in winding inductance coils or magnets, it is called a stranded wire and not a cable. If it is substantially insulated, it is called a "cord," defined below.)

Cord. A small cable, very flexible and substantially insulated to withstand wear. (There is no sharp dividing line in respect to size between a "cord" and a "cable," and likewise no sharp dividing line in respect to the character of insulation between a "cord" and a "stranded wire." Usually the insulation of a cord contains rubber.)

Concentric Strand.—A strand composed of a central core surrounded by one or more layers of helically laid wires or groups of wires.

Concentric Lay Cable.—A single-conductor cable composed of a central core surrounded by one or more layers of helically laid wires.

Rope Lay Cable.—A single-conductor cable composed of a central core surrounded by one or more layers of helically laid groups of wires. (This kind of cable differs from the preceding in that the main strands are themselves stranded.)

N-Conductor Cable.—A combination of N conductors insulated from one another. (It is not intended that the name as here given be actually used. One would instead speak of a "3-conductor cable," a "12-conductor cable," etc. In referring to the general case, one may speak of a "multiple-conductor cable," as in definition for "*Cable*" above).

N-Conductor Concentric Cable.—A cable composed of an insulated central conducting core with tubular stranded conductors laid over it concentrically and separated by layers of insulation. (Usually only 2-conductor or 3-conductor. Such conductors are used in

carrying alternating currents. The remark on the expression "N-conductor" given for the preceding definition applies here also.)

Duplex Cable.—Two insulated single-conductor cables twisted together. (They may or may not have a common insulating covering.)

Twin Cable.—Two insulated single-conductor cables laid parallel, having a common covering.

Triplex Cable.—Three insulated single-conductor cables twisted together. (They may or may not have a common insulating covering.)

Twisted Pair.—Two small insulated conductors twisted together, without a common covering. (The two conductors of a "twisted pair" are usually substantially insulated, so that the combination is a special case of a "cord.")

Twin Wire.—Two small insulated conductors laid parallel, having a common covering.

155A. The weights of wires, of the metals that are ordinarily used, can be computed for wires of any diameter and any length with the following formula, by using values from Table **156.**

$$W = k \times D^2 \times l \text{ or } D = \sqrt{\frac{W}{k \times l}}$$

or

$$W = k \times \text{cir. mil} \times l$$

Wherein W = weight in pounds, k = constant from **156,** differing in value for each metal and equal to the weight of a cir. mil-ft. of the metal, D = the diameter of the wire in mils or thousandths of an inch and l is the length of the wire in feet.

Example.—What is the weight of a bare 500,000 cir.-mil copper cable 2,000 ft. long?

Solution.—Substitute in the formula:

$$W = k \times \text{cir. mil} \times l = 0.00000303 \times 500{,}000 \times 2{,}000 = 3{,}030 \text{ lb.}$$

The wire will weigh 3,030 lb.

156. Weights of 1 Cir. Mil-ft. of Metals

Metal	k Weight in pounds of 1 cir. mil-ft.
Copper	0.00000303
Aluminum	0.000000916
Galvanized iron	0.00000264
Galvanized crucible steel	0.00000264

157. Wire Gages.—Diameters of wires are usually expressed according to some wire gage. Unfortunately there are many gages originated by different manufacturers for their products. Wire sizes are referred to by gage numbers and, usually, the smaller the number the bigger the wire. The ordinary uses of the different gages are indicated in **162.** The only legal gage in this country is the U. S. standard for plate. Wire-measuring gages (Figs. 89 and 90) are made of steel plate. With the kind shown in Fig. 89 the wire being measured is inserted in the slots in the periphery until a slot is found in which the wire just fits. Its gage number is indicated opposite the slot. A measuring gage

like that of Fig. 89 indicates the numbers of one gage or system only. A gage like that of Fig. 90 indicates the numbers of four gages but has the disadvantage that, to use it, the end of the wire must be available to push through the slot. The wire is pushed as far toward the small end of the slot as it will go and its gage number will be indicated opposite the point where the wire stops. The gage of Fig. 90 is arranged to indicate gage

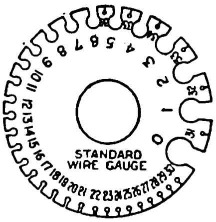


FIG. 89.—Standard wire gage (greatly reduced).

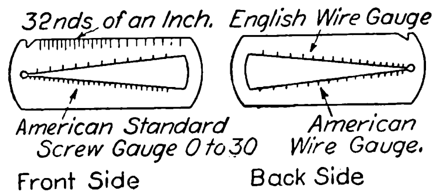


FIG. 90.—Angular wire gage (greatly reduced).

numbers for the American Screw Gage, English Wire Gage, American Wire Gage and one scale is divided into 32nds of an inch.

158. Wire gage systems and wire-measuring gages are inconvenient and confusing and the practice of **measuring wires and plates with a micrometer** (Fig. 91) is becoming prevalent. Some concerns now make a practice of specifying the diameters of all wires in thousandths of an inch and, doubtless, the practice will ultimately become universal. The micrometer measures

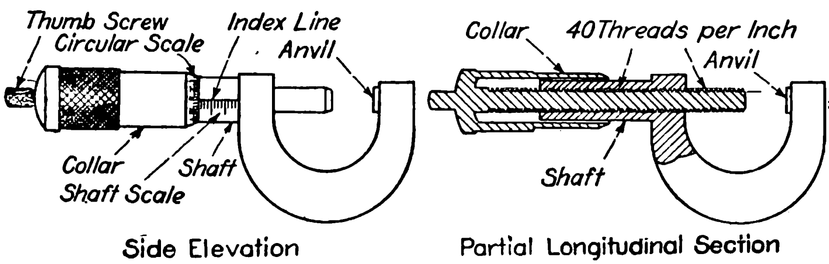


FIG. 91.—A micrometer caliper.

very accurately to thousandths of an inch and ten thousandths can be estimated. The wire to be measured is placed between the *thumb screw* and the *anvil* (Fig. 91) and the screw turned until the wire is lightly held between the screw and the anvil. The screw has 40 threads to the inch so that one complete turn of the screw in a left-handed direction will open the micrometer $\frac{1}{40}$ of an inch. On the edge of the *collar* is a *circular scale* divided into 25 divisions, hence, when the screw is turned through one of these divisions, the micrometer will open $\frac{1}{25}$ in. $\times \frac{1}{40}$ in. $= \frac{1}{1000}$ in. The *shaft* on which the *collar* turns is marked into tenths of an inch and each $\frac{1}{10}$ is subdivided into four parts. Each of these parts must be equal to $\frac{1}{10}$ in. by $\frac{1}{4}$ in. $= \frac{1}{40}$ in. $= 0.025$ in. Therefore a complete rotation of the collar or 25 of its divisions will equal one division of the shaft or 0.025 in.

159. To read a micrometer (see Fig. 92 and the paragraph above) note the number on the *circular scale* nearest the *index line*. This indicates the number of thousandths. Note the number of small divisions uncovered on the *shaft scale*. Each one of these small divisions indicates 0.025 in. ($\frac{25}{1000}$). Add together the number of thousandths indicated on the *circular* scale and 0.025 × the number of small divisions wholly uncovered on the shaft scale. The sum will be the distance that the jaws are apart.

Examples are shown in Fig. 92.

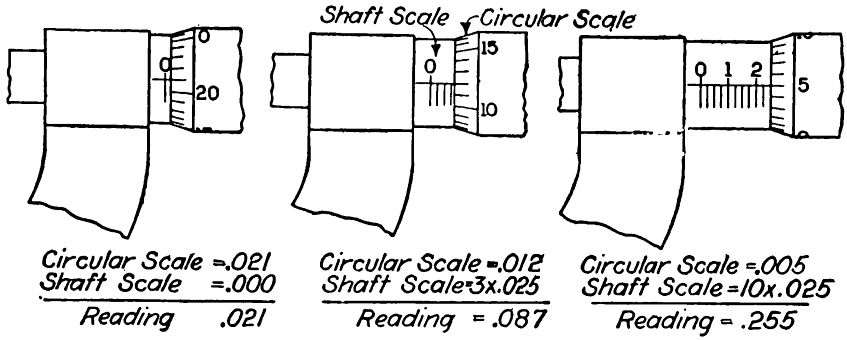


FIG. 92.—A micrometer caliper.

160. The most important of the different gages that are in use in this country are indicated by numerical comparison in Table **164**. Some of these gages are known by several names. The **different names for each gage** system, their abbreviations and the materials **ordinarily measured by each** are indicated in table **162**.

161. Tensile Strength of Pure Copper Wire in Pounds

Size, B. & S.	Hard drawn: Actual	Hard drawn: Average per square inch	Annealed: Actual	Annealed: Average per square inch	Size, B. & S.	Hard drawn: Actual	Hard drawn: Average per square inch	Annealed: Actual	Annealed: Average per square inch
0000	8,260	49,700	5,320	32,000	7	1050.0	64,200	556.0	34,000
000	6,550	49,700	4,220	32,000	8	843.0	65,000	441.0	34,000
00	5,440	52,000	3,340	32,000	9	678.0	66,000	350.0	34,000
0	4,530	54,600	2,650	32,000	10	546.0	67,000	277.0	34,000
1	3,680	56,000	2,100	32,000	12	343.0	67,000	174.0	34,000
2	2,970	57,000	1,670	32,000	14	219.0	68,000	110.0	34,000
3	2,380	57,600	1,323	32,000	16	138.0	68,000	68.9	34,000
4	1,900	58,000	1,050	32,000	18	86.7	68,000	43.4	34,000
5	1,580	60,800	884	34,000	19	68.8	68,000	34.4	34,000
6	1,300	63,000	700	34,000	20	54.7	68,000	27.3	34,000

162. Different Names, Abbreviations and Uses of the Principal Wire and Sheet Metal Gages

Column No. in Table 164	Common name and abbreviation	Other names and abbreviations	Ordinarily used for measuring
1	Brown & Sharpe (B. & S.).	American Wire Gage (A.W. G.). United States Standard. American Standard Wire Gage.	Almost universally used in America in lighting and power practice for measuring bare and insulated copper wire under ½ in. in diameter. All electrical wires and rod except those of iron and steel. All metal plates except those of copper, iron, steel and zinc. Thickness of wall of brazed brass, zinc and copper tubing.
2	Birmingham (B. W. G.).	Stubs Iron Wire Gage (Not Stubs Steel Wire Gage). Old English Standard (Not English Standard). Iron Wire Gage.	Galvanized iron and steel wire. Norway iron wire. Iron rivets, copper rivets. Thickness of wall of all seamless tubing except iron and steel. Sometimes used by A. T. & T. Co. for bare copper telephone line wire. Sheet copper.
3	Trenton.........	....	Trenton Iron Works iron wire. Quite similar to Washburn and Mohn Gage. Seldom used.
4	American Screw.	....	Numbered sizes of wood and machine screws, particularly those smaller than 0.2421 in. (No. 14).
5	New British Standard (N. B. S.).	Standard Wire Gage (S. W. G.). British Imperial (I. W. G.). English Legal Standard (S. W. G.). British Standard.	Seldom used in America in lighting and power practice. Used by some American telephone and telegraph companies for bare copper line wire.
6	Washburn & Mohn (W. & M.).	Roebling. American Steel and Wire Co's. Iron Wire Gage (A. S. W.). G. W. Prentiss Gage, Holyoke, Mass.	Iron and steel wire. Sometimes used for galvanized iron telephone and telegraph wire. Wire nails. Brass and iron escutcheon pins.

162. Different Names, Abbreviations and Uses of the Principal Wire and Sheet Metal Gages (*Continued*)

Column No. in Table 164	Common name and abbreviation	Other names and abbreviations	Ordinarily used for measuring
7	London Gage....	Old English (Not Old English Standard), from Brass Manufacturers list.	For brass wire, but seldom used.
8	Stubs Steel Wire Gage.	(Not Stubs Iron Wire Gage).	Drill rod.
9	Steel Music Wire Gage (M. W. G.).	Hammacher & Schlemmer (H. & S.). Felten & Guilleanme (F. & G.).	Steel music wire.
10	United States Standard (U. S. S.).	....	Iron and steel plate. This is the legal standard in America for these materials.

163. Equivalent Cross-sections of Wires

Brown & Sharpe Gage

Equivalent section	Number of wires of various sizes						
	2	4	8	16	32	64	128
0000	0	3	6	9	12	15	18
000	1	4	7	10	13	16	One each
00	2	5	8	11	14	17	1 and 3
0	3	6	9	12	15	18	2 " 4
1	4	7	10	13	16	..	3 " 5
2	5	8	11	14	17	..	4 " 6
3	6	9	12	15	18	..	5 " 7
4	7	10	13	16	..	..	6 " 8
5	8	11	14	17	..	..	7 " 9
6	9	12	15	18	..	..	8 " 10
7	10	13	16	..	..	..	9 " 11
8	11	14	17	..	..	..	10 " 12
9	12	15	18	..	..	..	11 " 13
10	13	16	..	..	..	..	12 " 14
11	14	17	..	..	..	..	13 " 15
12	15	18	..	..	..	..	14 " 16
13	16	..	..	..	..	..	15 " 17
14	17	..	..	..	..	..	16 " 18
15	18	..	..	..	..	..	..

Example.—Two No. 4, eight No. 10 and 32 No. 16 are all equivalent to a cross-section of one No. 1.

More current can be carried, with the same temperature rise, by using divided circuits. The greater the number of divided circuits, for the same equivalent cross-section, the greater the amount of current that the combination can carry. Consult Table **170** for safe carrying capacities of individual conductors.

164. Comparison of Wire

Dimensions in mils or

Gage No.	1 American. B. & S.	2 Birmingham Stubs.	3 Trenton	4 American Screw	5 British Imperial.
7-0	....	....	....	....	500.0
6-0	....	....	....	....	464.0
5-0	....	....	450.0	....	432.0
4-0	460.0	454.0	400.0	....	400.0
3-0	409.6	425.0	360.0	31.5	372.0
2-0	364.8	380.0	330.0	44.7	348.0
0	324.9	340.0	305.0	57.8	324.0
1	289.3	300.0	285.0	71.0	300.0
2	257.6	284.0	265.0	84.2	276.0
3	229.4	259.0	245.0	97.3	252.0
4	204.3	238.0	225.0	110.5	232.0
5	181.9	220.0	205.0	123.6	212.0
6	162.0	203.0	190.0	136.8	192.0
7	144.3	180.0	175.0	150.0	176.0
8	128.5	165.0	160.0	163.1	160.0
9	114.4	148.0	145.0	171.3	144.0
10	101.9	134.0	130.0	189.4	128.0
11	90.7	120.0	117.5	202.6	116.0
12	80.8	109.0	105.0	215.8	104.0
13	72.0	95.0	92.5	228.9	92.0
14	64.1	83.0	80.6	242.1	80.0
15	57.1	72.0	70.0	255.2	72.0
16	50.8	65.0	61.0	268.4	64.0
17	45.3	58.0	52.5	281.6	56.0
18	40.3	49.0	45.0	294.7	48.0
19	35.9	42.0	40.0	307.9	40.0
20	32.0	35.0	35.0	321.0	36.0
21	28.5	32.0	31.0	334.2	32.0
22	25.3	28.0	28.0	347.4	28.0
23	22.6	25.0	25.0	360.5	24.0
24	20.1	22.0	22.5	373.7	22.0
25	17.9	20.0	20.0	386.8	20.0
26	15.9	18.0	18.0	400.0	18.0
27	14.2	16.0	17.0	413.2	16.4
28	12.6	14.0	16.0	426.3	14.8
29	11.3	13.0	15.0	439.5	13.6
30	10.0	12.0	14.0	452.6	12.4
31	8.9	10.0	13.0	465.8	11.6
32	7.9	9.0	12.0	479.0	10.8
33	7.1	8.0	11.0	492.1	11.0
34	6.3	7.0	10.0	505.3	9.2
35	5.6	5.0	9.5	518.4	8.4
36	5.0	4.0	9.0	531.6	7.6
37	....	....	8.5	544.8	6.8
38	4.0	....	8.0	557.9	6.0
39	3.5	....	7.5	571.1	5.2
40	3.1	....	7.0	584.2	4.8

165. How to Remember the Brown & Sharpe Wire-gage Table (*Westinghouse Diary*).—A wire that is three sizes larger than another wire has half the resistance, twice the weight and twice the area. A wire that is ten sizes larger than another wire has one-tenth the resistance, ten times the weight and ten times the area. No. 10 wire is 0.10 in. in diameter (more precisely 0.102); it has an area of 10,000 cir. mils (more precisely 10,380); it has a resistance of 1 ohm per thousand feet at 20 deg. cent. (68 deg. fahr.), and weighs 32 lb. (more precisely 31.4 lb.) per thousand feet.

and Sheet Metal Gages

thousandths of an inch

6 W.&M. Roeb. A.S.W.	7 Old English London Gage	8 S.W.G.	9 H., S.&Co. "F.&G." Steel Music Wire Gage	10 U. S. Stand.	Gage No.
......	....	......	....	500.0	7–0
460.0	....	......	....	468.7	6–0
430.0	....	......	....	437.5	5–0
393.8	454.0	......	....	406.2	4–0
362.5	425.0	......	....	375.0	3–0
331.0	380.0	......	8.7	343.7	2–0
306.5	340.0	......	9.3	312.5	0
283.0	300.0	227.0	9.8	281.2	1
262.5	284.0	219.0	10.6	265.6	2
243.7	259.0	212.0	11.4	250.0	3
225.3	238.0	207.0	12.2	234.4	4
207.0	220.0	204.0	13.8	218.7	5
192.0	203.0	201.0	15.7	203.5	6
177.0	180.0	199.0	17.7	187.5	7
162.0	165.0	197.0	19.7	171.9	8
148.3	148.0	194.0	21.6	156.2	9
135.0	134.0	191.0	23.6	140.6	10
120.5	120.0	188.0	26.0	125.0	11
105.5	109.0	185.0	28.3	109.4	12
91.5	95.0	182.0	30.3	93.7	13
80.0	83.0	180.0	32.3	78.1	14
72.0	72.0	178.0	34.2	70.3	15
62.5	65.0	175.0	36.2	62.5	16
54.0	58.0	172.0	38.2	56.2	17
47.5	49.0	168.0	40.0	50.0	18
41.0	40.0	164.0	42.0	43.7	19
34.8	35.0	161.0	44.0	37.5	20
31.7	31.5	157.0	46.0	34.4	21
28.6	29.5	155.0	48.0	31.2	22
25.8	27.0	153.0	51.0	28.1	23
23.0	25.0	151.0	55.0	25.0	24
20.4	23.0	148.0	59.0	21.9	25
18.1	20.5	146.0	63.0	18.7	26
17.3	18.75	143.0	67.0	17.2	27
16.2	16.5	139.0	71.0	15.6	28
15.0	15.5	134.0	74.0	14.1	29
14.0	13.75	127.0	78.0	12.5	30
13.2	12.25	120.0	82.0	10.9	31
12.8	11.25	115.0	86.0	10.1	32
11.8	10.25	112.0	....	9.4	33
10.4	9.5	110.0	....	8.6	34
9.5	9.0	108.0	....	7.8	35
9.0	7.5	106.0	....	7.0	36
8.5	6.5	103.0	....	6.6	37
8.0	5.75	101.0	....	6.2	38
7.5	5.0	99.0	....	......	39
7.0	4.5	97.0	....	......	40

The weight of 1,000 ft. of No. 5 wire is 100 lb. The relative values of resistance (for decreasing sizes) and of weight and area (for increasing sizes) for *consecutive* sizes are: 0.50, 0.63, 0.80, 1.00, 1.25, 1.60, 2.00. The relative values of the diameters of *alternate* sizes of wire are: 0.50, 0.63, 0.80, 1.00, 1.25, 1.60, 2.00. To find resistance, drop one cipher from the number of circular mils; the result is the number of feet per ohm. To find weight, drop four ciphers from the number of circular mils and multiply by the weight of No. 10 wire.

166. Table of Wire Cables.

Number of wires used in cable		1	3	7	12	19	27
Inches per twist			$2\frac{1}{6}$	3	$4\frac{1}{6}$	5	$6\frac{1}{6}$
Sizes of wire in cable							Circular mils
B. & S. Ga. No.	Diam. mils	Circular mils					
30	0.0100	101	303	707	1212	1919	2727
29	0.0112	127	381	889	1524	2413	3429
28	0.0126	160	480	1120	1920	3040	4320
27	0.0142	202	606	1414	2424	3838	5454
26	**0.0159**	**254**	**762**	**1778**	**3048**	**4826**	**6858**
25	0.0179	321	963	2247	3852	6099	8667
24	0.0201	404	1212	2828	4848	7676	10908
23	0.0226	510	1530	3570	6120	9690	13770
22	0.0253	643	1929	4494	7716	12217	17361
21	**0.0285**	**810**	**2430**	**5670**	**9720**	**15390**	**21870**
20	0.0320	1022	3066	7154	12264	19418	27594
19	0.0359	1287	3861	9009	15444	24453	34749
18	0.0403	1624	4872	11368	19488	30856	43848
17	0.0452	2048	6144	14336	24576	38912	55295
16	**0.0508**	**2583**	**7749**	**18081**	**30996**	**49077**	**69741**
15	0.0571	3257	9771	22799	39084	61883	87939
061	0.0610	3733	11199	26131	44796	70927	100821
14	0.0641	4107	12321	28749	49284	78033	110889
065	0.0650	4225	12675	29575	50700	82725	114075
13	**0.0720**	**5179**	**15537**	**36253**	**62148**	**98401**	**139833**
075	0.0750	5632	16896	39424	67584	107008	152064
12	0.0808	6530	19590	45710	78360	124070	176310
083	0.0830	6905	20715	48335	82860	131195	186435
11	0.0907	8234	24702	57638	98808	156446	222318
095	**0.0950**	**9052**	**27156**	**63364**	**108624**	**171988**	**244404**
10	0.1019	10381	31143	72667	124572	197239	280287
9	0.1144	13094	39282	91658	157128	248746	353538
8	0.1285	16509	49527	105563	198108	313671	446743
7	0.1443	20816	62448	145712	....	....	....
6	0.1620	26251	78753	183757	....	....	....

167. Allowable Current-carrying Capacity of Copper Wires.—If there is too much current in a given conductor it will become so hot that it will be unsafe or may, if insulated, damage its insulation. Certain safe current values have been determined for different size conductors and some are listed in Table 170. Less current is permissible in rubber insulated wires than in wires insulated with other materials because relatively small temperature rises may injure rubber insulation. For interior wiring, the National Electrical Code values should be used, unless local municipal rules similar to the Chicago Rules are mandatory. A 50 deg. fahr. rise in temperature is permissible in bare line-wires suspended in air. The General Electric Co. values indicate what that concern recommends as safe practice, with an initial temperature of 20 deg. cent.

168. Slow-burning weather-proof conductors (Fig. 95) are sometimes used for interior exposed wiring in damp dark places, where there are corrosive vapors where the voltage does not exceed 550. They are cheaper than rubber-insulated conductors. The

Circular Mils in Strands. *The Benedict & Burnham Co.*

37	48	61	75	91	108	127	147	169
7	$8\frac{1}{6}$	9	$10\frac{1}{6}$	11	$12\frac{1}{6}$	13		

in cables

3737	4848	6161	7575	9191	10908	12827	14700	16900
4699	6096	7747	9525	11557	13716	16129	18522	21294
5920	7680	9760	11200	14560	17280	20320	23373	26871
7474	9696	12322	15150	18382	21816	25654	29547	33969
9398	**12192**	**15494**	**19050**	**23114**	**27432**	**32258**	**37338**	**42926**
11877	15408	19581	24075	29211	34668	40767	47040	54080
14948	19392	24644	30300	36764	43632	51308	59388	68276
18870	24480	31110	38250	46410	55080	64770	74823	86021
23791	30864	39223	48225	58513	69444	81661	94374	108498
29970	**38880**	**49410**	**60750**	**73710**	**87480**	**102870**	**119070**	**136890**
37814	49056	62342	76650	93002	110376	129794	150087	172549
47619	61766	78507	96525	117117	138996	163449	189189	217503
60088	77952	99064	121800	147784	175392	206248	238728	274456
75775	98304	124928	153600	186368	221184	260096	301056	346112
95571	**123984**	**157563**	**193725**	**235053**	**278964**	**328041**	**379554**	**436358**
120509	156336	198677	244375	296387	351756	413639	478632	550264
138131	179184	227713	279975	339703	403164	474091	546987	628849
151959	197136	250527	308025	373737	443656	521589	603582	693914
156325	202800	257725	316875	384475	556300	536575	621075	714025
191623	**248592**	**315919**	**388425**	**471289**	**559332**	**651733**	**761166**	**875082**
208384	270336	343552	422390	512512	608256	715264	826875	950625
241610	313440	398330	489750	594230	705240	829310	959763	1103401
255485	331440	421205	517875	628355	745740	876935	1012683	1164241
304658	395232	502274	617550	749294	889272	1045718	1210398	1391546
334924	**434496**	**552172**	**678900**	**822822**	**977616**	**1149604**	**1326675**	**1525225**
384097	498288	633241	778575	944671	1121148	1318387	1526007	1754389
484478	628512	798934	982050	1191554	1414152	1662938	1924818	2212886
610833	792432	1007049	1238175	1502319	1782972	2096643	2426823	2790021
......	......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	......	......

insulation consists of an inner weather-proof coating and an outer fire-resisting coating. The code requires that the fire-resisting coating be $\frac{6}{10}$ the thickness of the entire coating. To meet this condition the manufacturers use one weather-proof braid and two fire-resisting braids. The fire-resisting compound consists of a mixture containing white lead, oxide of zinc, chalk, or some similar substance. The outer braid is rubbed smooth on the outside. The manufacture of slow-burning weather-proof conductors has been discontinued by some manufactures and they are now seldom used.

Wires with a fire-resisting outer coating have the advantage that dust and lint do not readily adhere to their outer surfaces, as is often the case with weather-proofed braids. If dust does collect, it can be easily swept off. Slow-burning weather-proof wire is cheaper than slow-burning wire. It is not suitable for out-of-door service. See Table 177 for properties.

169. Dimensions, Weights and Resistances of

American or Brown & Sharpe's

B. & S. or American Wire Gage No.	Diam., inches	Area		Carrying capacities		Weight. Sp. gr. 8.9	
		Circular mils. (d^2) 1 m. = 0.001 in.	Sq. mils. ($d^2 \times 0.7854$)	Rubber ins., amps.	Other ins., amps.	Lbs. per 1,000 ft.	Pounds per mile
0000	0.460000	211600.00	166190.0	225	325	639.33	3375.7
000	0.409640	167805.00	131790.0	175	275	507.01	2677.0
00	0.364800	133079.40	104520.0	150	225	402.09	2123.0
0	0.324860	105538.00	82887.0	125	200	318.86	1683.6
1	0.289300	83694.20	65733.0	100	150	252.88	1335.2
2	0.257630	66373.00	52130.0	90	125	200.54	1058.8
3	0.229420	52634.00	41339.0	80	100	159.03	839.68
4	0.204310	41742.00	32784.0	70	90	126.12	665.91
5	0.181940	33102.00	25998.0	55	80	100.01	528.05
6	0.162020	26250.50	20617.0	50	70	79.32	418.81

No. 6 and larger conductors, where they are to be used in interior work or outside pole-line construction, solid wires up to and including No. 00 can the greater ease of handling stranded conductors. See Table 175 for proper-

B. & S. or American Wire Gage No.	Diam., inches	Circular mils.	Sq. mils.	Rubber ins., amps.	Other ins., amps.	Lbs. per 1,000 ft.	Pounds per mile
7	0.144280	20816.00	16349.0	38	54	62.90	332.11
8	0.128490	16509.00	12966.0	35	50	49.88	263.37
9	0.114430	13094.00	10284.0	28	38	39.56	208.88
10	0.101890	10381.00	8153.2	25	30	31.37	165.63
11	0.090742	8234.00	6467.0	20	27	24.88	137.37
12	0.080808	6529.90	5128.6	20	25	19.73	104.18
13	0.071961	5178.40	4067.1	14	.....	15.65	82.632
14	0.064048	4106.70	3225.4	15	20	12.44	65.674
15	0.057068	3256.70	2557.8	.....	.....	9.84	51.956
16	0.050820	2582.90	2028.6	6	10	7.81	41.237
17	0.045257	2048.20	1608.6	.....	.....	6.19	32.683
18	0.040303	1624.30	1275.7	3	5	4.91	25.925
19	0.035876	1287.10	1011.69	.....	.....	3.88	20.507
20	0.031961	1021.50	802.28	The above		3.09	16.315
21	0.028462	810.10	636.25	values are		2.45	12.936
22	0.025347	642.70	504.78	those speci-		1.94	10.243
23	0.022571	509.45	400.12	fied in the		1.54	8.1312
24	0.020100	404.01	317.31	1915		1.22	6.4416
25	0.017900	320.40	251.64	National		0.97	5.1216
26	0.015940	254.01	199.50	Electrical		0.77	4.0656
27	0.014105	201.50	158.26	Code.		0.61	3.2208
28	0.012641	159.79	125.50	In lighting		0.48	2.5344
29	0.011257	126.72	99.526	work, no		0.38	2.0064
30	0.010025	100.50	78.933	wire smaller		0.30	1.5840
31	0.008928	79.71	62.604	than No.		0.24	1.2672
32	0.007950	63.20	49.637	14 is used,		0.19	1.0032
33	0.007080	50.13	39.372	except in		0.15	0.7920
34	0.006304	39.74	31.212	fixtures		0.12	0.6336
35	0.005614	31.52	24.756	....		0.10	0.5280
36	0.005000	25.00	19.635	....		0.08	0.4224
37	0.004453	19.83	15.567	....		0.06	0.3168
38	0.003965	15.72	12.347	....		0.05	0.2640
39	0.003531	12.47	9.7939	....		0.04	0.2112
40	0.003144	9.89	7.7676	....		0.03	0.1581

[1] Calculated on the basis of Dr. Matthiesen's standard, namely, 1 mil. of 59-9 deg. Fahr.

Pure, Solid, Bare Copper Wire.[1] (Approximate)

Gage (*Benedict & Burnham Co.*).

Length		Resistance at 75 deg. Fahr.			B. & S. or American Wire Gage No.
Feet per lb.	Feet per ohm, 75 deg. F.	R. ohms per 1,000 ft.	Ohms per mile	Ohms per lb.	
1.56	20383.0	0.04906	0.25903	0.000076736	0000
1.97	16165.0	0.06186	0.32664	0.00012039	000
2.49	12820.0	0.07801	0.41187	0.00019423	00
3.14	**10166.0**	**0.09838**	**0.51937**	**0.00038500**	**0**
3.95	8062.3	0.12404	0.65490	0.00048994	1
4.99	6393.7	0.15640	0.82582	0.00078045	2
6.29	5070.2	0.19723	1.0414	0.0012406	3
7.93	4021.0	0.24869	1.3131	0.0019721	4
10.00	**3188.7**	**0.31361**	**1.6558**	**0.0031361**	**5**
12.61	2528.7	0.39546	2.0881	0.0049868	6
15.90	2005.2	0.49871	2.6331	0.0079294	7
20.05	1590.3	0.62881	3.3201	0.012608	8
25.28	1261.3	0.79281	4.1860	0.020042	9
31.38	**1000.0**	**1.0000**	**5.2800**	**0.031380**	**10**
40.20	793.18	1.2607	6.6568	0.050682	11
50.69	629.02	1.5898	8.3940	0.080585	12
63.91	498.83	2.0047	10.585	0.12841	13
80.38	395.60	2.5278	13.347	0.20322	14
101.63	**321.02**	**3.1150**	**16.477**	**0.31658**	**15**
128.14	248.81	4.0191	21.221	0.51501	16
161.59	197.30	5.0683	26.761	0.81900	17
203.76	156.47	6.3911	33.745	1.3023	18
257.47	123.99	8.0654	42.585	2.0759	19
324.00	**98.401**	**10.163**	**53.658**	**3.2926**	**20**
408.56	78.067	12.815	67.660	5.2355	21
515.15	61.911	16.152	85.283	8.3208	22
649.66	49.087	20.377	107.59	13.238	23
819.21	38.918	25.695	135.67	21.050	24
1032.96	**30.864**	**32.400**	**171.07**	**33.466**	**25**
1302.61	24.469	40.868	215.79	35.235	26
1642.55	19.410	51.519	272.02	84.644	27
2071.22	15.393	64.966	343.02	134.56	28
2611.82	12.207	81.921	432.54	213.96	29
3293.97	**9.6812**	**103.30**	**545.39**	**340.25**	**30**
4152.22	7.8573	127.27	671.99	528.45	31
5236.66	6.0880	164.26	867.27	860.33	32
6602.71	4.8290	207.08	1093.4	1367.3	33
8328.30	3.8281	261.23	1379.3	2175.5	34
10501.35	**3.0363**	**329.35**	**1738.9**	**3458.5**	**35**
13238.83	2.4082	415.24	2192.5	5497.4	36
16691.06	1.9093	523.76	2765.5	8742.1	37
20854.65	1.5143	660.37	3486.7	13772.0	38
26302.23	1.2012	832.48	4395.5	21896.0	39
33175.94	0.9527	1049.7	5542.1	34823.0	40

are to be drawn into conduits, should be cables so they will be flexible. For be used but for larger conductors cables should be employed because of ties of bare cables.

pure copper wire of $\frac{1}{16}$ in. diameter equals 13.59 ohms at 15.5 deg. cent. or

170. Allowable or Safe Carrying

(Voltage drop is not taken into account in this

American or Brown and Sharpe gage number	Diam. of solid wire in mils	Area in circular mils	II National Electrical Code (inside wiring) 1915 Rules					
			Table A. Rubber insulation, amps.	Table B. Other insulations, amps.	C Drop in volts per 1,000 ft. of wires (500 ft. 2-wire circuit) with allowable currents		D Length in feet of 2-wire circuit (single distance) over which N.E.C. safe currents can be transmitted with 1-volt drop, assuming 11 ohms the resistance of a cir. mil foot of commercial copper wire	
					Table A. Rubber insulation, volts	Table B. Other insulations, volts	Table A	Table B
18[1]	40.3	1,624	3	5	......	......	....	....
16[1]	50.8	2,583	6	10	......	......	....	....
14	64.1	4,107	15	20	40.2	53.5	12.4	9.4
12	80.8	6,530	20	25	33.8	42.2	14.8	11.9
10	101.9	10,380	25	30	26.6	31.8	18.9	15.8
8	128.5	16,510	35	50	23.3	33.3	21.4	15.0
6	162.0	26,250	50	70	20.9	29.4	23.9	17.0
5	181.9	33,100	55	80	18.3	26.6	27.4	18.8
4	204.3	41,740	70	90	18.5	23.7	27.1	21.1
3	229.4	52,630	80	100	16.7	21.0	29.9	23.9
2	257.6	66,370	90	125	14.9	20.8	33.5	24.1
1	289.3	83,690	100	150	13.1	19.7	38.1	25.4
0	325.0	105,500	125	200	13.0	20.8	38.4	24.0
00	364.8	133,100	150	225	12.4	18.6	40.4	26.9
000	409.6	167,800	175	275	11.5	18.0	43.7	27.8
....	......	200,000	200	300	11.0	16.5	45.5	30.3
0000	460.0	211,600	225	325	11.7	16.9	42.7	29.6
		250,000	240	350	10.5	15.4	47.5	32.5
		300,000	275	400	10.0	14.7	49.5	34.0
		350,000	300	450	9.4	14.2	53.0	35.4
		400,000	325	500	8.9	13.8	56.0	36.4
		500,000	400	600	8.8	13.2	56.8	37.9
		600,000	450	680	8.2	12.5	60.6	40.2
		700,000	500	760	7.8	11.9	63.6	41.9
		800,000	550	840	7.5	11.5	66.5	43.3
		900,000	600	920	7.3	11.2	68.2	44.5
		1,000,000	650	1,000	7.1	11.0	70.0	45.5
		1,100,000	690	1,080	6.9	10.8	72.5	46.3
		1,200,000	730	1,150	6.7	10.5	74.8	47.5
		1,300,000	770	1,220	6.5	10.3	76.8	48.5
		1,400,000	810	1,290	6.4	10.1	78.6	49.5
		1,500,000	850	1,360	6.2	9.9	80.5	50.2
		1,600,000	890	1,430	6.1	9.8	81.8	50.8
		1,700,000	930	1,490	6.0	9.6	83.0	52.0
		1,800,000	970	1,550	5.9	9.5	84.5	52.8
		1,900,000	1,010	1,610	5.8	9.3	85.5	53.7
		2,000,000	1,050	1,670	5.7	9.2	86.5	55.5

[1] Wires smaller than No. 14 American Wire Gage shall not be used except

170A. The allowable or safe current-carrying capacity of aluminum wire is, where the wire is insulated, specified in the *Nat. Elec. Code* as 84 per cent. of the values for copper wire (with the same insulation) which are given in *Columns A* and *B* in **170.**

171. **Slow-burning conductors** (Fig. 95) are insulated with three braids impregnated with a fire-resisting compound, the same that is used on slow-burning weather-proof conductors. They are approved (N.E.C.) for interior exposed wiring, in dry places,

Capacity of Copper Wires, Amperes

table and should be considered separately)

E Bare wires in still air; temp. rise 50 deg. fahr. Std. U. G. Cable Co., amps.	General Electric Co., low tension cable Single conductor F Rubber insulation, 30 deg. cent. rise, amps.	General Electric Co., low tension cable Single conductor G Varnished cambric ins. or paper, 60 deg. cent. rise, amps.	General Electric Co., low tension cable Triple conductor H 30 deg. cent. rise, amps.	Circular mils	I National Electrical Code (inside wiring) 1911 Rules Now Obsolete Table A. Rubber insulation, amps.	I National Electrical Code (inside wiring) 1911 Rules Now Obsolete Table B. Other insulations, amps.
6.0	....	....	....	[1]1,624	3	5
8.5	....	....	....	[2]2,583	6	8
12.1	22	....	18	4,107	12	16
17.1	28	....	24	6,530	17	23
24.3	37	24	31	10,380	24	32
41.5	47	36	40	16,510	33	46
58.8	57	60	56	26,250	46	65
69.7	74	72	63	33,100	54	77
83.3	89	81	74	41,740	65	92
98.8	105	96	87	52,630	76	110
117.6	119	120	99	66,370	90	131
140.0	145	143	120	83,690	107	156
169.8	168	178	140	105,500	127	185
201.5	196	220	162	133,100	150	220
240.2	227	272	188	167,800	177	262
274.5	263	310	215	200,000	200	300
286.0	270	331	221	211,600	210	312
324.6	306	390	252	250,000	235	350
373.0	343	450	285	300,000	270	400
419.0	381	510	315	350,000	300	450
463.0	416	560	347	400,000	330	500
549.0	487	660	403	500,000	390	590
631.0	557	770	455	600,000	450	680
708.0	621	870	515	700,000	500	760
781.0	677	970	....	800,000	550	840
852.0	735	1,060	....	900,000	600	920
922.0	792	1,150	....	1,000,000	650	1,000
991.0	854	1,230	....	1,100,000	690	1,080
1,058.0	908	1,300	....	1,200,000	730	1,150
1,123.0	960	1,370	....	1,300,000	770	1,220
1,187.0	1,010	1,440	....	1,400,000	810	1,290
1,250.0	1,060	1,500	....	1,500,000	850	1,360
1,312.0	1,110	1,560	....	1,600,000	890	1,430
1,373.0	1,158	1,605	....	1,700,000	930	1,490
1,433.0	1,200	1,650	....	1,800,000	970	1,550
1,492.0	1,248	1,700	....	1,900,000	1,010	1,610
1,550.0	1,290	1,750	....	2,000,000	1,050	1,670

for fixture and signal wiring and pendant cords.

where the voltage does not exceed 550. They are particularly applicable for hot, dry places wherein ordinary insulations would soon perish. The outer braid is finished like that for slow-burning weather-proof conductors and has the same properties. See 177.

172. **Weather-proof slow-burning conductors** have a fire-resisting coating next to the conductor and a weather-proof coating on the outside. They are approved by the N.E.C.

173. Properties of Rubber-insulated Wire and Cable.

(Standard Underground Cable Co. See

Size B. & S.	Area cir. mils	*A* Dia. bare mils	*B* Insulation 64th in.	Solid wire				Stranded or cable	
				Single braid		Double braid		Single braid	
				C Dia. mils	Lb. per 1,000 ft.	*D* Dia. mils	Lb. per 1,000 ft.	Dia. mils	Lb. per. 1,000 ft.
.....	....	.....	.....	.....	....	.....	....	.....	....
18	1,624	40	2	143	14.5	185	19.1	.....	....
16	2,582	51	2	155	18.9	197	23.9	.....	....
14	4,106	64	3	208	33.0	258	40.0	216	34.3
12	6,530	81	3	225	43.1	275	51.5	235	44.9
10	10,381	102	3	246	58.1	296	67.2	260	60.6
9	13,094	114	3	258	68.4	308	78.2	274	70.0
8	16,509	128	3	273	82.1	322	92.2	290	85.5
6	26,251	162	4	337	130.0	387	142.0	360	136.0
5	33,102	182	4	357	154.0	407	167.0	396	166.0
4	41,742	204	4	393	190.0	457	208.0	422	198.0
3	52,634	229	4	418	228.0	482	247.0	451	238.0
2	66,373	258	4	447	276.0	511	297.0	504	293.0
1	83,694	289	5	530	363.0	614	395.0	571	377.0
0	105,593	325	5	565	439.0	649	474.0	613	457.0
00	133,100	365	5	605	528.0	689	564.0	659	556.0
000	167,805	410	5	650	646.0	734	685.0	709	675.0
0000	211,600	460	5	700	793.0	784	835.0	767	833.0

174. Rubber-covered or rubber-insulated wires and cables (see Fig. 93), when protected with one braid over the insulation, are known as single-braid, and when two braids are used, to insure against injury by abrasion, they are known as double-braid rubber-covered wire or cable. Rubber-covered conductors are used for inside wiring where concealed or in damp places and throughout where the voltage exceeds 550. Conductors insulated with less expensive materials (see following paragraphs) can be used out-of-doors, on pole lines and inside in dry places where the wires are exposed. The use of single-braid rubber-covered wires is permissible for exposed interior wiring in damp places and in wooden and metal moulding in dry places and in iron conduit, provided the wire is smaller than No. 6. Double braid wires should be used in all cases where the wire is larger than No. 6. Table 173 gives the principal properties of rubber-covered conductors, for pressures not exceeding 600 volts.

National Electrical Code Standard, 0-600 Volts

illustration below for key to reference letters)

Size B. & S.	Stranded or cable		Stranded or cable						
	Double braid					Single braid		Double braid	
	Dia. mils	Lb. per 1,000 ft.	*E* Size cir. mils	*B* Insulation 64th in.	Dia. bare mils	*F* Dia. mils	Lb. per 1,000 ft.	*G* Dia. mils	Lb. per 1,000 ft.
....	......	....	250,000	6	575	845	997	929	1,047
18	......	....	300,000	6	630	902	1,173	986	1,226
16	......	....	350,000	6	681	952	1,343	1,036	1,399
14	268	42.4	400,000	6	729	1,001	1,514	1,085	1,573
12	285	53.8	450,000	6	773	1,044	1,685	1,128	1,746
10	310	70.1	500,000	6	815	1,087	1,842	1,171	1,906
9	324	80.0	550,000	7	855	1,157	2,053	1,241	2,121
8	340	96.3	600,000	7	893	1,194	2,220	1,278	2,290
6	410	149.0	650,000	7	929	1,231	2,389	1,315	2,461
5	460	184.0	700,000	7	964	1,266	2,557	1,350	2,631
4	486	218.0	750,000	7	998	1,300	2,723	1,384	2,798
3	515	260.0	800,000	7	1,031	1,333	2,891	1,417	2,968
2	588	324.0	850,000	7	1,062	1,365	3,056	1,449	3,135
1	655	412.0	900,000	7	1,093	1,395	3,223	1,479	3,304
0	697	494.0	950,000	7	1,123	1,425	3,388	1,509	3,470
00	743	595.0	1,000,000	7	1,152	1,455	3,553	1,539	3,637
000	793	719.0	1,250,000	8	1,289	1,623	4,506	1,707	4,599
0000	851	879.0	1,500,000	8	1,413	1,747	5,344	1,831	5,445
....	......	....	1,750,000	8	1,526	1,860	6,177	1,944	6,284
....	......	....	2,000,000	8	1,631	1,965	7,006	2,049	7,119

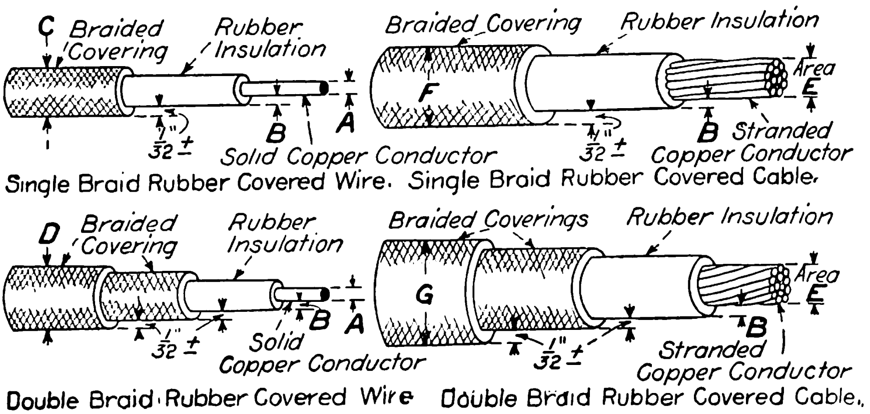


FIG. 93.—National electrical code, rubber-insulated, wire and cable (See Table 173)

175. Physical and Electrical Properties of Pure Copper Stranded Cable (*Standard Underground Cable Co.*)

Size, B. & S. gage and area cir. mils	No. of wires in strand	Dia. of wires in strand, mils	Diameter of bare cable		Approx. weight in lbs.		Approx. ft. per lb.	Approx. ft. per ohm	Approx. resistance international ohms at 68 deg. fahr.	
			Mils	In 64th of inch	Per 1,000 ft.	Per mile			Per 1,000 ft.	Per lb.
14	7	24.2	73	5	13	69	77	397	2.52	0.194
12	7	30.5	92	6	20	106	50	632	1.59	0.0795
10	7	38.5	116	8	32	169	31	1,005	0.997	0.0312
8	7	48.6	146	10	50	264	20	1,598	0.627	0.0125
6	7	61.2	184	12	80	422	12.5	2,540	0.394	0.00493
5	7	68.8	206	14	101	533	9.90	3,203	0.313	0.00310
4	7	77.2	232	15	127	670	7.87	4,031	0.248	0.00195
3	7	86.7	260	17	160	845	6.25	5,084	0.197	0.00123
2	7	97.4	292	19	202	1,067	4.95	6,410	0.156	0.000772
1	19	66.4	328	22	255	1,346	3.92	8,083	0.124	0.000486
1/0	19	74.5	373	24	322	1,700	3.11	10,190	0.098	0.000304
2/0	19	83.7	419	27	406	2,144	2.46	12,850	0.078	0.000192
3/0	19	94.0	470	31	512	2,704	1.95	16,210	0.062	0.000121
4/0	19	105.5	528	33	646	3,405	1.55	20,440	0.049	0.0000759
250,000	37	82.2	575	37	764	4,023	1.34	24,150	0.041	0.0000550
300,000	37	90.1	630	41	917	4,842	1.09	28,980	0.035	0.0000382
350,000	37	97.3	681	44	1,070	5,650	0.935	33,800	0.030	0.0000280
400,000	37	104.0	729	47	1,223	6,457	0.818	38,630	0.026	0.0000213
450,000	37	110.3	773	50	1,377	7,271	0.726	43,460	0.023	0.0000167
500,000	61	90.5	815	53	1,530	8,078	0.653	48,290	0.021	0.0000137
550,000	61	95.0	855	55	1,684	8,891	0.594	53,100	0.019	0.0000113
600,000	61	99.2	893	58	1,837	9,700	0.544	58,000	0.017	0.00000925
650,000	61	103.2	929	60	1,991	10,810	0.502	62,800	0.016	0.00000804
700,000	61	107.1	964	62	2,145	11,330	0.466	67,600	0.015	0.00000700
750,000	61	110.9	998	64	2,299	12,140	0.435	72,400	0.014	0.00000609
800,000	61	114.5	1,031	67	2,453	12,950	0.408	77,300	0.013	0.00000530
900,000	61	121.5	1,093	71	2,762	14,580	0.362	86,900	0.012	0.00000435
1,000,000	61	128.0	1,152	74	3,070	16,210	0.326	96,600	0.010	0.00000359
1,250,000	91	117.2	1,289	83	3,882	20,500	0.258	120,800	0.0083	0.00000214
1,500,000	91	128.4	1,413	91	4,631	24,450	0.216	144,900	0.0069	0.00000149
1,750,000	127	117.4	1,526	98	5,428	28,660	0.184	169,000	0.0059	0.00000111
2,000,000	127	125.5	1,631	105	6,200	32,740	0.161	193,200	0.0052	0.000000839

176. Properties of National Code Standard, Rubber-covered, Solid and Stranded Wire and Cable For Voltages of 600 to 1,500.

Standard Underground Cable Co.

Size		No. of wires in cond.	Diam. of wires comprising cable, mils	Thickness of rubber in inches	Diameter over all				Approx. weight per 1,000 ft., tape and braid
					Single braid		Double braid		
B. & S. gage	Cir. mils				Mils	64ths	Mils	64ths	
				Solid					
14	4,107	.....	....	1/16	239	15.3	289	18.5	46
12	6,530	.....	....	1/16	256	16.4	306	19.6	58
10	10,380	.....	....	1/16	277	17.75	327	20.9	75
8	16,510	.....	....	1/16	304	19.45	354	22.6	100
6	26,250	.....	....	5/64	382	24.2	446	28.5	153
4	41,740	.....	....	5/64	425	27.2	489	31.3	212
2	66,370	.....	....	5/64	498	31.9	582	37.2	310
1	83,690	.....	....	3/32	561	35.9	645	41.25	394
1/0	105,500	.....	....	3/32	596	38.2	680	43.5	475
2/0	133,100	.....	....	3/32	636	40.65	720	46.1	595
3/0	167,800	.....	....	3/32	681	43.5	765	48.96	700
4/0	211,600	.....	....	3/32	732	46.8	816	52.2	850
				Stranded					
8	16,510	7	48.6	1/16	321	20.5	371	23.75	106
6	26,250	7	61.2	5/64	404	25.8	468	30.0	160
4	41,740	7	77.2	5/64	453	29.0	517	33.1	225
2	66,370	7	97.4	5/64	532	34.1	616	39.4	320
1	83,690	19	66.4	3/32	604	38.65	688	44.0	405
1/0	105,500	19	74.5	3/32	645	41.25	729	46.6	490
2/0	133,100	19	83.7	3/32	691	44.25	775	49.6	595
3/0	167,800	19	94.0	3/32	742	47.5	826	52.8	715
4/0	211,600	19	105.5	3/32	800	51.2	884	56.5	875
....	250,000	37	82.2	7/64	878	56.2	962	61.5	1,040
....	300,000	37	90.1	7/64	933	59.7	1,017	65.2	1,220
....	350,000	37	97.3	7/64	984	63.0	1,068	68.5	1,390
....	400,000	37	104.0	7/64	1,032	66.0	1,116	71.4	1,570
....	450,000	37	110.3	7/64	1,076	68.9	1,160	74.3	1,745
....	500,000	61	90.6	7/64	1,118	71.5	1,202	76.9	1,915
....	600,000	61	99.2	1/8	1,227	78.5	1,311	83.9	2,300
....	650,000	61	103.2	1/8	1,263	80.9	1,347	86.3	2,470
....	700,000	61	107.1	1/8	1,298	83.1	1,382	88.5	2,640
....	750,000	61	110.9	1/8	1,332	85.3	1,416	90.6	2,810
....	800,000	61	114.5	1/8	1,365	87.4	1,449	92.8	2,930
....	900,000	61	121.5	1/8	1,327	91.5	1,511	96.75	3,330
....	1,000,000	61	128.0	1/8	1,486	95.2	1,570	100.5	3,670

177. Properties of Weather-proof and Slow-burning

Size, B. & S. and cir. mils	Weather-proof				Slow-burning
	Approx. wts. per 1,000 ft.		Approx. overall diameters, in.		Approx. wts. per 1,000 ft.
	Triple braid	Double braid	Triple braid	Double braid	Weather-proof white finish
			Solid wire		
0000	765	710	0.660	0.610	870
000	625	570	0.595	0.560	720
00	490	448	0.550	0.515	568
0	400	360	0.505	0.470	470
1	310	290	0.445	0.405	350
2	255	232	0.400	0.374	290
4	164	146	0.346	0.320	200
6	112	97	0.303	0.278	140
8	75	64	0.264	0.245	95
10	53	46	0.221	0.197	70
12	35	27	0.200	0.172	52
14	25	20	0.182	0.155	40
16	19	15	0.169	0.142	30
18	16	12	....	....	24
20	12	9	....	....	....
			Stranded Wire or Cable		
2,000,000	6,700	6,540	1.930	1.844	....
1,750,000	5 894	5,739	1.820	1.740	....
1,500,000	5,090	4,940	1.712	1.624	....
1,250,000	4,287	4,153	1.580	1.500	....
1,000,000	3,478	3,360	1.451	1.365	3,880
900,000	3,290	3,045	1.390	1.310	3,540
800,000	2,778	2,700	1.331	1.243	3,200
750,000	2,615	2,551	1.300	1.210	3,020
700,000	2,439	2,380	1.265	1.177	2,840
600,000	2,113	2,060	1.190	1.105	2,370
500,000	1,781	1,740	1.108	1.027	2,010
450,000	1,630	1,598	1.070	0.984	1,840
400,000	1,445	1,405	1.020	0.940	1,670
350,000	1,277	1,240	0.978	0.894	1,460
300,000	1,126	1,090	0.930	0.846	1,290
250,000	937	905	0.862	0.780	1,080
0000	806	753	0.785	0.708	910
000	655	610	0.728	0.648	745
00	515	470	0.662	0.599	590
0	420	382	0.605	0.555	485
1	328	300	0.518	0.470	360
2	267	251	0.440	0.415	300
4	173	153	0.379	0.353	205
6	117	103	0.327	0.305	145
8	75	69	0.290	0.270	97

For number of wires in strand see 183.

Solid Copper Wire and Cable. (*General Electric Co.*)

Slow-burning					Size, B. & S. and cir. mils.
Approx. weights per 1,000 ft.		Approx. overall diameters, inches			
Weather-proof black finish	Under-writers	Weather-proof or white	Weather-proof or black	Under-writers	
Solid wire					
862	780	0.660	0.660	0.660	0000
710	640	0.595	0.595	0.595	000
562	510	0.550	0.550	0.550	00
462	420	0.505	0.505	0.505	0
340	**330**	**0.445**	**0.445**	**0.445**	**1**
280	280	0.400	0.400	0.400	2
190	180	0.346	0.346	0.346	4
127	125	0.303	0.303	0.303	6
85	90	0.264	0.264	0.264	8
60	**65**	**0.221**	**0.221**	**0.221**	**10**
42	40	0.200	0.200	0.200	12
30	30	0.182	0.182	0.182	14
24	22	0.169	0.169	0.169	16
19	....	....	....	....	18
....	....	....	....	....	20
Stranded Wire or Cable					
7,540	....	1.930	1.930	1.930	2,000,0C
6,700	....	1.820	1.820	1.820	1,750,00
5,830	....	1.712	1.712	1.712	1,500,000
4,940	....	1.580	1.580	1.580	1,250,000
3,980	**3,578**	**1.451**	**1.451**	**1.451**	**1,000,000**
3,640	3,250	1.390	1.390	1.390	900,000
3,280	2,894	1.331	1.331	1.331	800,000
3,100	2,720	1.300	1.300	1.300	750,000
2,920	2,540	1.265	1.265	1.265	700,000
2,460	**2,204**	**1.190**	**1.190**	**1.190**	**600,000**
2,080	1,858	1.108	1.108	1.108	500,000
1,900	1,700	1.070	1.070	1.070	450,000
1,700	1,509	1.020	1.020	1.020	400,000
1,500	1,329	0.978	0.987	0.978	350,000
1,310	**1,170**	**0.930**	**0.930**	**0.930**	**300,000**
1,120	981	0.862	0.862	0.862	250,000
960	844	0.785	0.785	0.785	0000
785	686	0.728	0.728	0.728	000
625	550	0.662	0.662	0.662	00
510	**449**	**0.605**	**0.605**	**0.605**	**0**
380	360	0.518	0.518	0.518	1
335	294	0.440	0.440	0.440	2
230	196	0.379	0.379	0.379	4
165	135	0.327	0.327	0.327	6
105	**94**	**0.290**	**0.290**	**0.290**	**8**

178. Properties of National Code Standard, Rubber-covered, Solid and Stranded Wire and Cable For Voltages of 1,500 to 2,500.

Standard Underground Cable Co.

Size: B.&S. gage	Size: Cir. mils	No. of wires in cond.	Diam. of wires compris-ing cable, mils	Thick-ness of rubber in inches	Diameter over all: Single braid, Mils	Single braid, 64ths	Double braid, Mils	Double braid, 64ths	Approx. weight per 1,000 ft., tape and braid
				Solid					
14	4,107	.....	....	$\frac{3}{32}$	302	19.3	352	22.5	70
12	6,530	.....	....	$\frac{3}{32}$	318	20.4	368	23.55	85
10	10,380	.....	....	$\frac{3}{32}$	339	21.7	389	24.9	100
8	16,510	.....	....	$\frac{3}{32}$	380	24.3	444	28.4	130
6	26,250			$\frac{3}{32}$	414	26.5	478	30.6	175
4	41,740	.....	....	$\frac{3}{32}$	456	29.2	520	33.3	240
2	66,370	.....	....	$\frac{3}{32}$	509	32.6	573	36.65	330
1	83,690	.....	....	$\frac{7}{64}$	592	37.0	676	43.25	420
1/0	105,500	.....	....	$\frac{7}{64}$	628	40.2	712	45.5	500
2/0	133,100	.....	....	$\frac{7}{64}$	668	42.75	752	48.1	600
3/0	167,800	.....	....	$\frac{7}{64}$	712	45.5	796	50.1	725
4/0	211,600	.....	....	$\frac{7}{64}$	763	48.8	847	54.25	875
				Stranded					
8	16,510	7	48.6	$\frac{3}{32}$	398	25.5	462	29.6	140
6	26,250	7	61.2	$\frac{3}{32}$	436	27.9	500	32.0	185
4	41,740	7	77.2	$\frac{3}{32}$	504	32.25	588	37.6	250
2	66,370	7	97.4	$\frac{3}{32}$	564	36.1	648	41.5	340
1	83,690	19	66.4	$\frac{7}{64}$	635	40.6	719	46.0	435
1/0	105,500	19	74.5	$\frac{7}{64}$	676	43.25	760	48.6	520
2/0	133,100	19	83.7	$\frac{7}{64}$	721	46.1	805	51.5	620
3/0	167,800	19	94.0	$\frac{7}{64}$	773	49.5	857	54.8	745
4/0	211,600	19	105.5	$\frac{7}{64}$	831	53.2	915	58.5	905
....	250,000	37	82.2	$\frac{1}{8}$	909	58.1	993	63.5	1,080
....	300,000	37	90.1	$\frac{1}{8}$	964	61.7	1,048	67.1	1,255
....	350,000	37	97.3	$\frac{1}{8}$	1,015	65.0	1,099	70.4	1,430
....	400,000	37	104.0	$\frac{1}{8}$	1,063	68.0	1,147	73.4	1,610
....	450,000	37	110.3	$\frac{1}{8}$	1,107	70.9	1,191	76.3	1,785
....	500,000	61	90.6	$\frac{1}{8}$	1,149	73.5	1,233	78.9	1,990
....	600,000	61	99.2	$\frac{9}{64}$	1,258	80.6	1,342	85.9	2,350
....	650,000	61	103.2	$\frac{9}{64}$	1,294	82.9	1,378	88.2	2,525
....	700,000	61	107.1	$\frac{9}{64}$	1,329	85.1	1,413	90.45	2,710
....	750,000	61	110.9	$\frac{9}{64}$	1,363	87.25	1,447	92.7	2,875
....	800,000	61	114.5	$\frac{9}{64}$	1,396	89.4	1,480	94.8	3,050
....	900,000	61	121.5	$\frac{9}{64}$	1,458	93.4	1,542	98.8	3,490
....	1,000,000	61	128.0	$\frac{9}{64}$	1,517	97.25	1,601	102.4	3,730

179. Duplex or twin wires or cables (sometimes called "conduit wire") are shown in Fig. 94. They are used where they are to be drawn into conduit and should never be used except in conduit. Each wire is rubber-insulated to the thickness indicated in Table

180 and then is served with a braid or with a tape. The two conductors are finally bound together with a tenacious braid at least $\frac{1}{32}$ in. thick for wires larger than No. 10 B. & S. gage and

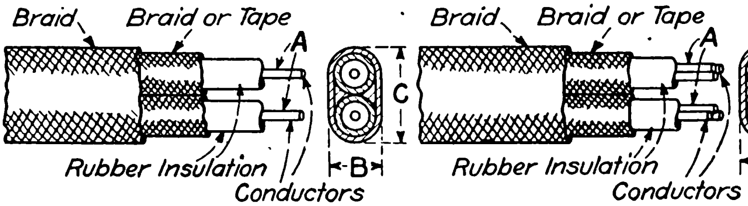


FIG. 94.—Duplex wire and cable.

$\frac{1}{64}$ in. for No. 10 B. & S. gage or less in size. This construction is considered in the N.E.C. as equivalent to that of double-braid, rubber-covered wire. Twin conductors larger than No. 0000 should not be used because of their tendency to kink.

180. National Electric Code Standard, Duplex (Flat), Two-conductor Wire and Cable, 0-600 Volts

(*General Electric Co.*)

A Size of each conductor B. & S. gage	Solid			Stranded		
	Weight in lbs. per 1,000 ft.	Dimensions in inches		Weight in lbs. per 1,000 ft.	Dimensions in inches	
		B	*C*		*D*	*E*
8	214	0.33	×0.57	214	0.35	×0.61
10	162	0.30	×0.52	162	0.32	×0.55
12	126	0.28	×0.46	126	0.29	×0.48
14	100	0.26	×0.42	100	0.27	×0.44

181. **Weather-proof wire or Cable** (Fig. 95) is used for out-of-door conductors and should be supported on porcelain or glass insulators and not on knobs, cleats or rubber hooks.* Weather-proof wire is not approved for inside wiring (N.E.C.) except where exposed to corrosive vapors. The so-called "weather-proof" insulation becomes a reasonably good conductor when moist. **Triple-braid** weather-proof conductors have three braids, saturated with a so-called moisture-proof compound served around them, and **double-braid** conductors have two such braids. Triple-braid conductors are approved by the N.E.C. for outside construction, but double-braid conductors are not approved at all. See Table 177 for properties.

182. **Safe Current-carrying Capacity of Large Fiber-cored Cables on A.-C. Circuits.**—See Fig. 96 for reference letters. Alternating current flowing in large cables has greater density on the surface of the conductor than in the center (so-called skin effect) therefore an ordinary cable will not carry as much alternating current as direct current with the same temperature rise. In order to overcome this it is advisable, on single-conductor cables 700,000 cm. and larger for 60-cycle circuits, and 1,250,000 cm. and larger

for 25-cycle circuits, to make the cable with a fiber core and strand the copper around it. The weight of copper in this type of cable is the same per foot as in an ordinary cable, but owing to its annular

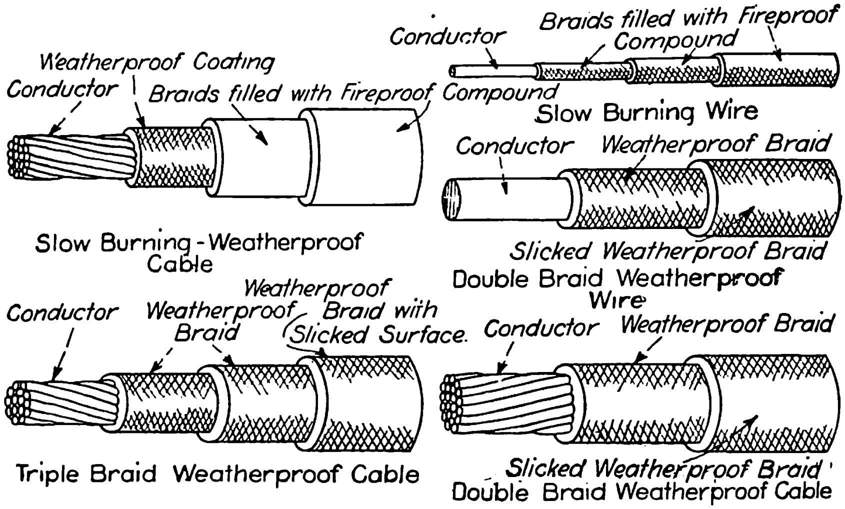


FIG. 95.—Weather-proof and slow-burning conductors.

cross-section the cable is much more efficient in carrying alternating current and also has a somewhat greater current-carrying capacity due to the larger radiating surface. These copper strands can be insulated with any desired type of insulation. (*General Electric Co.*)

182A. Fiber cord cables.

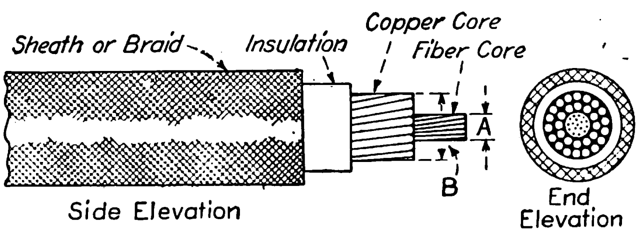


FIG. 96.—Cable with fiber core.

Size	*A* Dia. fiber core in in.	No. of wires in strand	Size wire in strand in in.	*B* Overall dia. copper core in in.	Ampere capacity 30 deg. cent. rise.	Ampere capacity 60 deg. cent. rise.
2,000,000	7/8	210	0.099	2.065	1,400	1,750
1,750,000	25/32	210	0.091	1.87	1,300	1,625
1,500,000	11/16	182	0.091	1.78	1,200	1,500
1,250,000	9/16	168	0.086	1.59	1,150	1,400
1,000,000	15/32	98	0.102	1.28	900	1,150
800,000	11/32	51	0.125	1.1	775	925
750,000	10/32	48	0.125	1.060	750	900
700,000	9/32	51	0.117	0.99	700	830
50,000	1/4	45	0.1056	0.890	550	660

183. Special Stranding Table for Weather-proof Slow-burning and Bare Cables.—*General Electric Co.* The price of any weather-proof, slow-burning or bare cable depends upon the size wire used in the strand. The finer the individual wires the more expensive the cable. The following table of strands insures a minimum price for the cable. Strands or cables from finer wires can be manufactured.

Size B. & S. and cir. mils	No. wires in strand	Diam. of individual wires in inches	Approximate diam. of bare cable in inches	Approximate weight of copper per 1,000 ft. in lb.
8	7	0.0485	0.1455	51
6	7	0.0613	0.1839	81
5	7	0.0688	0.2064	103
4	7	0.0773	0.2319	129
3	7	0.0868	0.2604	164
2	7	0.0974	0.2922	206
1	7	0.1110	0.3330	259
0	7	0.1250	0.3750	328
00	7	0.1400	0.4190	414
000	7	0.1560	0.4700	520
0000	19	0.1056	0.5280	658
250,000	19	0.1160	0.5754	775
300,000	19	0.1270	0.6342	943
350,000	19	0.1370	0.6818	1087
400,000	37	0.1040	0.7280	1242
450,000	37	0.1110	0.7770	1415
500,000	37	0.1170	0.8154	1554
550,000	37	0.1220	0.8550	1709
600,000	37	0.1280	0.8928	1864
650,000	37	0.1330	0.9297	2020
700,000	37	0.1380	0.9648	2177
750,000	61	0.1110	0.9990	2333
800,000	61	0.1146	1.0314	2487
900,000	61	0.1216	1.0944	2813
1,000,000	61	0.1281	1.1529	3110
1,250,000	61	0.1440	1.2903	3888
1,500,000	91	0.1284	1.4124	4660
1,750,000	91	0.1390	1.5262	5435
2,000,000	127	0.1255	1.6315	6212

184. Splices in bare copper line wire can be made as indicated in Fig. 97 and should be mechanically and electrically secure before solder is applied. There should be at least 5 turns in the neck (Fig. 97) of a splice to insure that the unsoldered splice will be as strong as the wire of which it is made. All splices in wires

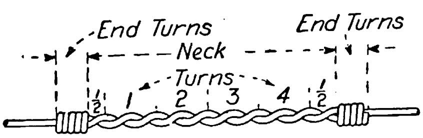


FIG. 97.—Bare copper, line wire splice.

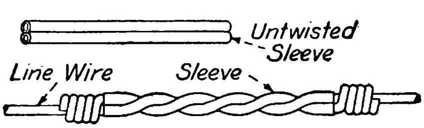


FIG. 98.—Splice made with McIntire sleeve.

for conveying electricity should be soldered in the neck. It is not always necessary to solder the end turns. McIntire sleeves are very satisfactory and are used to a great extent for splicing aerial line wires. (See Fig. 98.) Solder is not necessary where sleeves

are used. For further information in regard to splices in bare wire see *Electrical World*, Nov. 17, 1910, "Some Tests on Splices in Galvanized Iron Wire," By C. T. Rashman.

184A. **Splices in insulated aerial line wires** are made similarly to that shown in Fig. 97 except tape is served around the splice for insulation. (See Fig. 99.) If the line wire has only weatherproof insulation, friction tape is sufficient but if the inner insulation is rubber, rubber tape to the thickness of the inner insulation should be applied before the friction tape is served. All splices in wires for conveying electricity should be soldered in the neck.

185. **Instructions for Making a Joint in Pure Rubber Insulated Wire** (*Okonite Co.*). (See Fig. 100.) 1. *Preparing the Conductor Ends.*—Bare and clean about 1 in. of each end of the conductor; then, with a very sharp thin-bladed knife, bevel the insulation for about 1 in. as one would sharpen a lead pencil. 2. Preferably

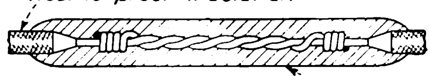


FIG. 99.—Splices and taps in insulated line wire.

make the conductor joint with a copper sleeve, sweating the latter on, being careful to clean off all surplus solder or, if the connection is made by twisting the two ends together, see that the ends do not protrude. 3. Now cover the bevels and conductor with a thin coat of a pure rubber cement and allow this to "set" (which takes about 1 min.).

4. *Insulating the Joint.*—Take a strip of $\frac{3}{4}$-in. pure rubber tape 6 to 8 in. long, and beginning at the bevel on a level with the insulation *A* in Fig. 100, wrap spirally (making sure that the turns overlap) to the other side of the joint as far as the high point of the bevel on that side, *B*. Continue to wrap to and fro until the insulation is built up slightly thicker than the regular wall. The tape must be put on under tension—say stretched to about half its width. Care must be taken to have everything perfectly clean.

FIG. 100.—Splicing rubber-insulated conductor with copper sleeve.

5. *To Partially Vulcanize the Joint.*—Apply heat from a spirit lamp, a lighted match or the heat of the hand evenly around the joint. Do this for about 1 min. (be careful not to burn the insulation) and then wrap the joint with two layers of $\frac{3}{4}$-in. friction tape. If the wire is braided or taped, be sure that the braid or tape is cut well back so that there are no loose threads overhanging to interfere with the proper insulating of the joint.

This is the method of making a joint *properly*, and, with slight modifications, it is applicable to all sizes of conductors.

Should the friction tape become slightly set, as it sometimes does in extreme cold weather, warming will restore it perfectly.

186. Splices in Interior Wires (Fig. 101).—Not as many turns are necessary in the neck as for aerial line wires. All splices must be soldered unless made with some form of approved splicing device. Rubber tape to the thickness of the rubber insulation must be used on rubber-covered wires and friction tape must be served over the rubber to hold it in place. The so-called "Fixture Splice" (Fig. 101) is used largely by telephone men and in wiring fixtures. It can be conveniently used sometimes in splicing two wires that must be drawn taut in the splicing. A splice in wires is often made at a point between two supports, cleats, or knobs in this way. The duplex wire splice (Fig. 101) is often used by telephone men. The joints should always be "broken," that is, they should not be opposite one another. In conduit work, for which duplex wire is frequently used, joints are not permissible except in junction boxes, but nevertheless they are occasionally made as indicated and pulled into conduit. Rubber and friction tape is applied to each in the same way as to the joint in a single wire and then the pair of wires should be served with friction tape. Joints should always be taped so that the insulation over the joint equals that over the rest of the conductor.

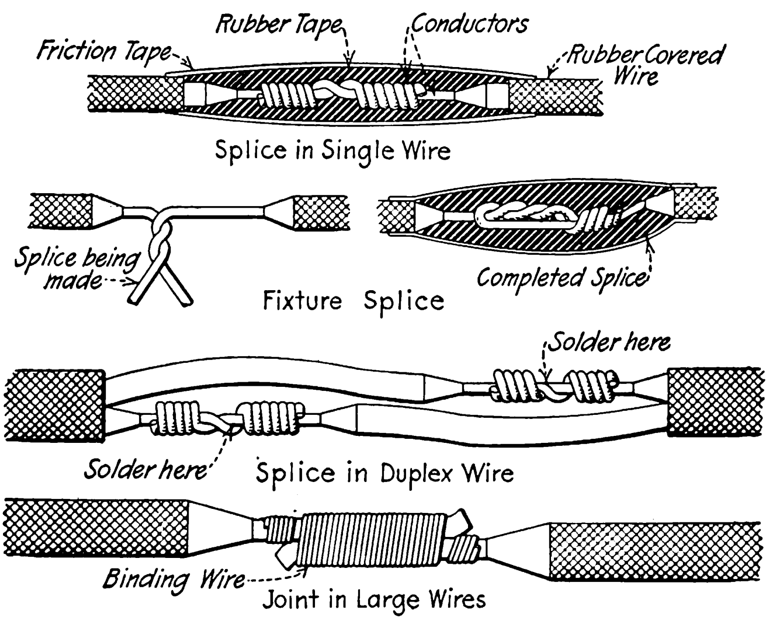


FIG. 101.—Splices in interior wires.

187. Taps in copper wires are made as shown in Fig. 102. The "knotted" tap has the advantage that the tap wire cannot untwist from the main wire. Tape should be applied as with

splices. The tap for small aerial wires, Fig. 102, is made by giving the tap wire one long complete wrap around the main wire and then four short turns. The long wrap gives the joint a certain amount of flexibility which is necessary for aerial work where wires are moved

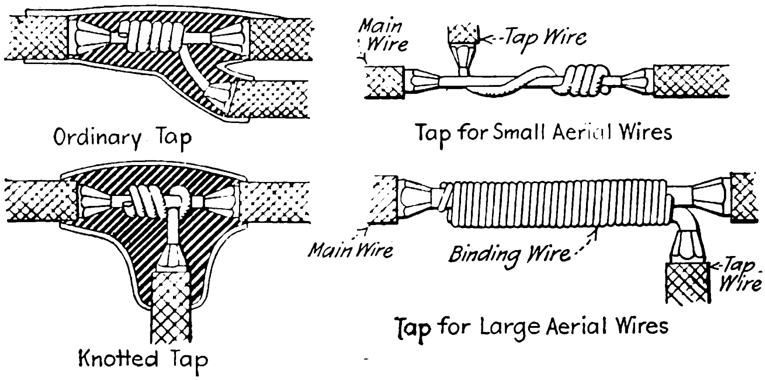


FIG. 102.—Methods of making taps from copper conductors.

by the wind. The tap for large wires is made by serving a binding wire about bared portions of the tap and main wires and then soldering the whole.

188. Joints in cables are made as shown in Fig. 103. The

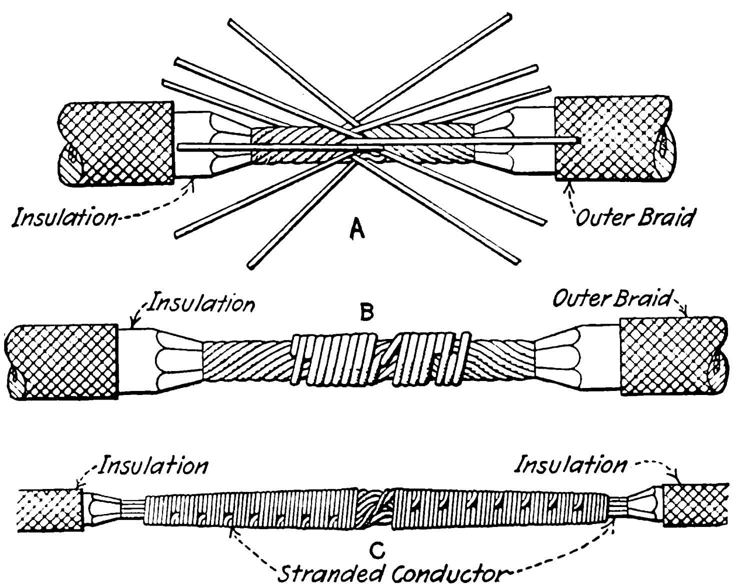


FIG. 103.—Methods of joining cables.

wires composing the cable should be spread and each pulled out straight and the core or a few inner wires cut away so that the splice will not be bulky. Then the two cable ends are abutted as shown in *A* (Fig. 103) and the wires are interwoven in groups of two each

and served along the cable. The joint is soldered by pouring, with a ladle, molten solder through and over it, the solder pot being meanwhile held under the joint so as to catch any solder that does not adhere. For interior work a short joint like that of *B* is frequently used, but in aerial work a longer one like that of *C* is preferred. For an aerial joint (*C*) a length of about 16 to 20 in. is bared at the end of each cable in order to make a splice. All of these joints should be thoroughly soldered.

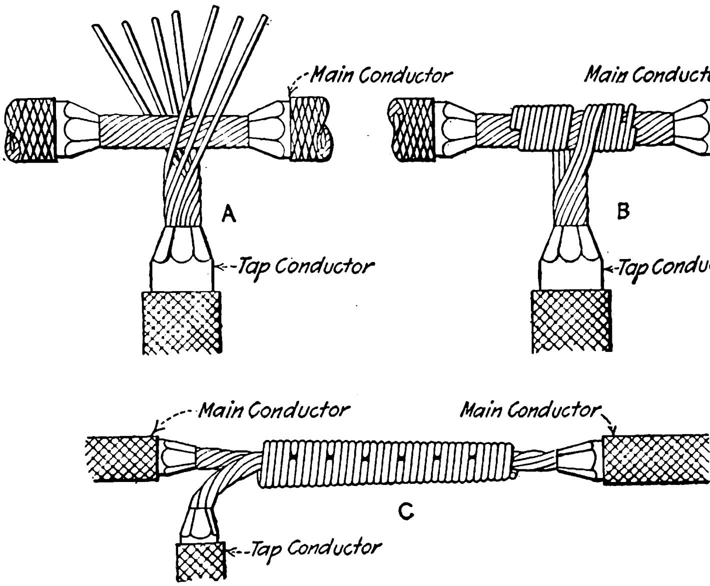


FIG. 104.—Tap joints in cables.

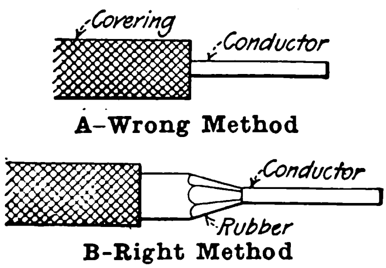


FIG. 105.—Methods of "skinning" wire.

189. Tap joints in Cables are made as suggested in Fig. 104. "*A*" shows how the tap wires are "fanned" out before being served about the main conductor and *B* shows a completed tap joint for interior work. *C* shows a completed tap joint in an aerial cable. Tap joints in cables can be made with a binding wire similarly to the method of Fig. 102.

190. In making any joint the wire ends should be scraped bright with the back of a knife blade, sand paper or emery paper so that the solder will adhere readily. Insulation should be cut away as

shown at *B* (Fig. 105) rather than as shown at *A*. When cut as at *A* the wire is likely to be nicked and with the *B* method the tape can be served more neatly about the joint. The outer braid should be cut well back from the joint so that stray strands from it cannot be taped into the joint and, by capillary attraction, conduct moisture thereto.

191. For soldering joints the non-corrosive fluid of **201** is recommended.

192. Circular Millage and Carrying Capacity in Amperes of Flat Bus-bar Copper (*Electrical Engineer's Equipment Co.*)

	Circular mils	1,000 C. M. per ampere or 1,273 amp. per sq. in.	1,200 C. M. per ampere or 1,061 amp. per sq. in.	1,600 C. M. per ampere or 795 amp. per sq. in.
⅛ in. bar copper				
By 1 in.	159154	159	133	99
By 1½ in.	238731	239	199	149
By 2 in.	318309	318	265	199
By 2½ in.	397886	398	332	249
By 3 in.	477463	477	398	298
By 3½ in.	557040	557	464	348
By 4 in.	636618	637	531	398
By 5 in.	795772	796	663	497
By 6 in.	954927	955	796	597
¼ in. bar copper				
By 1 in.	318309	318	265	199
By 1½ in.	477463	477	398	298
By 2 in.	636618	637	531	398
By 2½ in.	795772	796	663	497
By 3 in.	954927	955	796	597
By 3½ in.	1114081	1,114	928	696
By 4 in.	1273236	1,273	1,061	796
By 5 in.	1591545	1,592	1,326	995
By 6 in.	1909854	1,910	1,592	1,194
⅜ in. bar copper				
By 1 in.	477463	477	398	298
By 1½ in.	716194	716	597	448
By 2 in.	954927	955	796	597
By 2½ in.	1193658	1,194	995	746
By 3 in.	1432390	1,432	1,194	895
By 3½ in.	1671122	1,671	1,393	1,044
By 4 in.	1909854	1,910	1,592	1,194
By 5 in.	2387317	2,387	1,989	1,492
By 6 in.	2864781	2,865	2,387	1,790
½ in. bar copper				
By 1 in.	636618	637	531	398
By 1½ in.	954927	955	796	597
By 2 in.	1273236	1,273	1,061	796
By 2½ in.	1591545	1,592	1,326	995
By 3 in.	1909854	1,910	1,592	1,194
By 3½ in.	2228163	2,228	1,857	1,393
By 4 in.	2546472	2,546	2,122	1,592
By 5 in.	3183090	3,183	2,653	1,989
By 6 in.	3819708	3,820	3,183	2,387

193. **Bus-bars** are usually made up of rolled copper bar from 0.25 to 0.375 in. thick and from 1 in. in width up. When more than one bar is needed to give the required current-carrying capacity the bars are separated by means of spacing blocks so as to give a maximum radiating surface. Copper bars are designed on the basis of a **current density** of about 800 to 1,000 amp. per sq. in. of cross-section. They are mounted on insulators, the type of insulator depending upon the voltage of the system. Occasionally aluminum bus-bars, employing a maximum current density of about 750 amp. per sq. in., have been installed. For medium size plants, operating at a potential of 2,300 volts, the bus-bars are made up of insulated wires, varnished cambric being preferred as the insulating material, and these are mounted on insulators attached to the framework which supports the panels. **Contact surfaces** between bus-bars should allow between 100 and 200 amp. per sq. in. of surface, and **terminals and leads** taken from the bars should allow 100 amp. per sq. in. Brass castings for **connections and terminals** have a conductivity between 12 and 18 per cent., and, therefore, it is best to use copper where large current-carrying capacity is desired.

194. **Aluminum.**—The weight of aluminum is 0.000,000,915 (or 91.5×10^{-8}) lb. per cir. mil-ft. or 0.000,000,808 (or 80.8×10^{-8}) lb. per sq. mil-ft. (*Standard Handbook*). See additional values giving properties of aluminum in adjacent comparative table. The following data is from the *Westinghouse Diary:*

	Copper	Aluminum
Area for equal conductivity	100.0	160.0
Diameter for equal conductivity	100.0	126.0

It will be noted from the relative diameters that an aluminum wire to be of equal conductivity to a copper wire is almost exactly two sizes larger by B. & S. Gage.

The conductivity of aluminum wire is 63 per cent. of that of copper; but an aluminum wire of equivalent conductivity will have 48 per cent. of the weight and 160 per cent. of the strength.

195. **Commercial galvanized-iron wire** is known in the market by the following terms: **Extra Best Best** (E.B.B.).—This is made by improved continuous processes from the very best iron. It has the best conductivity of any commercial iron wire. Its weight per mile-ohm is from 4,600 to 5,100 lbs. It is very uniform in quality, pure, tough and pliable. **Best Best** (B.B.).—This is less uniform and tough than the above (E.B.B.), but stands a good mechanical test. Its weight per mile-ohm is 5,500 to 5,800 lbs. It is largely used by telephone and telegraph companies and in railway telegraph service. **Best** (B.) is a term applied almost indiscriminately to the lower grades of iron wire for electric service. It is a harder and a less pliable wire than the two above grades. Its weight per mile-ohm is about 6,500 lbs. **Steel** is a stiff wire of high tensile strength and low conductivity. It is very difficult to work, but is used on short lines that must be erected at low cost, where conductivity is of little importance. Its weight per mile-ohm is 6,000 to 7,000 lbs.

196. Properties of Galvanized Telephone and Telegraph Wires

Based on Standard Specifications (*American Steel & Wire Co.*)

Size B. W. G.	Diameter in mils = d	Area in circular mils = d^2	Approximate weight in pounds		Approximate breaking strain in pounds			Resistance per mile (international ohms) at 68 deg. fahr. or 20 deg. cent.		
			Per 1,000 ft.	Per mile	Ex. B.B.	B.B.	Steel	Ex. B.B.	B.B.	Steel
0	340	115,600	313	1,655	4,138	4,634	4,965	2.84	3.38	3.93
1	300	90,000	244	1,289	3,223	3,609	3,867	3.65	4.34	5.04
2	284	80,656	218	1,155	2,888	3,234	3,465	4.07	4.85	5.63
3	259	67,081	182	960	2,400	2,688	2,880	4.90	5.83	6.77
4	238	56,644	153	811	2,028	2,271	2,433	5.80	6.91	8.01
5	220	48,400	131	693	1,732	1,940	2,079	6.78	8.08	9.38
6	203	41,209	112	590	1,475	1,652	1,770	7.97	9.49	11.02
7	180	32,400	87	463	1,158	1,296	1,389	10.15	12.10	14.04
8	165	27,225	74	390	975	1,092	1,170	12.05	14.36	16.71
9	148	21,904	60	314	785	879	942	14.97	17.84	20.70
10	134	17,956	49	258	645	722	774	18.22	21.71	25.29
11	120	14,400	39	206	515	577	618	22.82	27.19	31.55
12	109	11,881	32	170	425	476	510	27.65	32.94	38.23
13	95	9,025	25	129	310	347	372	37.90	45.16	52.41
14	83	6,889	19	99	247	277	297	47.48	56.56	65.66
15	72	5,184	14	74	185	207	222	63.52	75.68	87.84
16	65	4,225	11	61	152	171	183	77.05	91.80	106.55

197. The so-called galvanized-steel strand (Fig. 106) is really seven-strand cable composed of galvanized steel wires. It is used for guying and for **messenger cable** to support cables that have not themselves much mechanical strength. It is also used for **long spans in transmission lines** which (*American Steel & Wire Co.*)

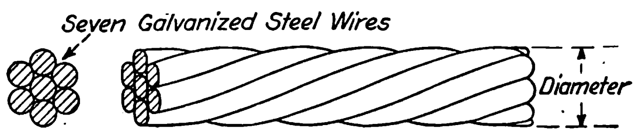


FIG. 106.—Galvanized steel strand.

cannot always be made with copper cables, because hard-drawn copper has a strength of only 65,000 lbs. per square inch. Where it is necessary to cross rivers with transmission lines, the energy may be conducted by one of the galvanized-steel cables tabulated, which should be of such size and strength that it will show a safety factor of at least five. It is not necessary to suspend bare copper cables beneath a steel strand, as the steel strand itself serves as the conductor. The ordinary or Bessemer steel cable is commonly used for guying and for supporting single suspension trolley wires, while the other grades are commonly used for messenger wires and for long transmission-spans.

198. Galvanized Steel Strand or Cable (*American Steel & Wire Co.*)

All of these are seven-strand cables

Ordinary or Bessemer steel				Extra galvanized Siemens-Martin					Extra galvanized high-strength or crucible steel					Extra galvanized extra high or plow steel				
Diam., in.	Approx. weight per 1,000 ft., pounds	Approx. strength, pounds	List prices per 100 ft.	Diam., in.	Actual breaking strength, pounds	List prices per 100 ft.	Elastic limit, per cent.	Per cent. elongation in 24 in.	Diam., in.	Actual breaking strength, pounds	List prices per 100 ft.	Elastic limit, per cent.	Per cent. elongation in 24 in.	Diam., in.	Actual breaking strength, pounds	List prices per 100 ft.	Elastic limit, per cent.	Per cent. elongation in 24 in.
5/8	....	......	......	..	19,000	$4.35	50	10.0	..	25,000	$6.25	55	6	..	42,500	$8.75	60	4
1/2	510	8,500	$4.50	..	11,000	2.80	50	10.0	..	18,000	3.95	55	6	..	27,000	5.50	60	4
7/16	415	6,500	3.75	..	9,000	2.30	50	10.0	..	15,000	3.45	55	6	..	22,500	4.60	60	4
3/8	295	5,000	2.75	..	6,800	1.80	50	10.0	..	11,500	2.70	55	6	..	17,250	3.55	60	4
5/16	210	3,800	2.25	..	4,860	1.35	50	10.0	..	8,100	2.10	55	6	..	12,100	2.70	60	4
9/32	....	......	......	..	4,380	1.10	50	10.0	..	7,300	1.75	55	6	..	10,900	2.10	60	4
1/4	125	2,300	1.75	..	3,060	1.00	50	10.0	..	5,100	1.50	55	6	..	7,600	1.90	60	4
7/32	95	1,800	1.50	..	......	......	....	......	..	......	......	....	....	..	......	......	....	....
3/16	75	1,400	1.25	..	2,000	0.85	50	10.0	..	3,300	1.30	55	6	..	4,900	1.60	60	4
5/32	55	900	1.15	..	......	......	....	......	..	......	......	....	....	..	......	......	....	....
1/8	32	500	1.00	..	900	0.55	50	10.0	..	1,500	0.80	55	6	..	2,250	1.05	60	4
3/32	20	400	0.80	..	......	......	....	......	..	......	......	....	....	..	......	......	....	....

199. Galvanized iron or steel wires are spliced as shown in Fig. 97 and 5 turns are necessary in the neck of the splice to insure that the splice will be as strong as the wire. The strength of an unsoldered joint is determined by the number of turns in the neck. The end turns have but little holding power. Small **galvanized steel cables are joined** in the same way as are wires, as shown in Fig. 107. There should be 5 turns in the neck, as with wires, and a few end turns to finish off the joint. Soldering is unnecessary for guy

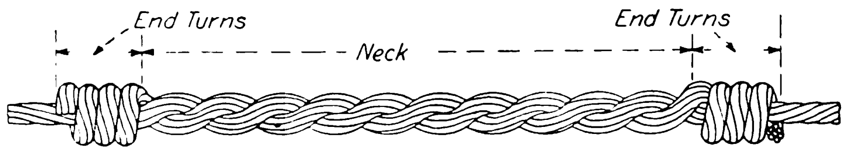


FIG. 107.—Joint in small steel cable.

wires. Larger cables can be spliced as shown in Fig. 103, or mechanical clamps can be used instead as shown in Fig. 108. Sometimes it is necessary to use several clamps, instead of one as the figure shows, in order that the joint will be as strong as the wire.

200. Methods of Soldering Wires in Terminal Lugs.—Where many terminal lugs are to be soldered to conductors a convenient and time-saving method of making the connections is to melt a pot of solder over a plumbers' furnace, heat the lug in the solder, pour the solder in the hole in the lug and then plunge the bared end of the conductor into it, as shown in Fig. 109. The insides of the holes of all commercial lugs are "tinned" so the solder adheres to them read-

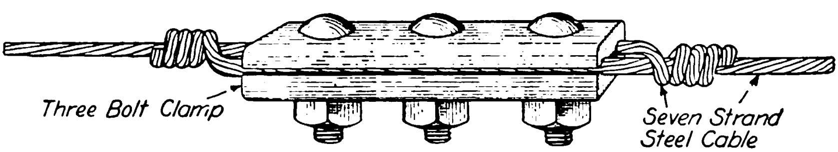


FIG. 108.—Steel cable joined with clamp.

ily, and the bared end of the conductor should also first be tinned. This may be done as follows: The end of the wire is carefully scraped with a knife or with a piece of fine sandpaper (the sandpaper is best because it cannot nick the wire) and then smeared with soldering flux and thrust into the solder pot. If a soldering stick is used the wire must be heated in the solder before the stick compound will melt and adhere. It requires but a short time to "tin" the wire end in the pot.

Immediately after the tinned end is pushed into the hole in the lug the lug should be soused with a piece of wet waste to cool it rapidly. Scrape or file off any shreds or globules of solder that adhered to the exposed surfaces of the lug and brighten it with fine sandpaper if necessary.

The insulation from the conductor ends should be cut back just far enough so that it will abut against the shoulder of the lug, as suggested in Fig. 110, *I*. The appearance is very unsightly and indicates careless work if there is a gap between the shoulder and the insulation, as at *II*. If because of some mishap a connection

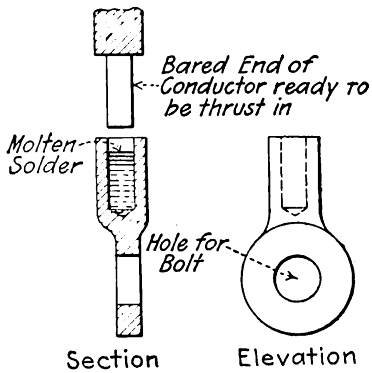


FIG. 109.—Soldering wire in lug.

results, having the appearance of *II*, a partial correction can be made by filling the gap with servings of tape, as shown at *III*. The tape of the standard $\frac{7}{8}$-in. width should be torn into strips about $\frac{1}{4}$ in. wide before applying.

Only enough molten solder should be poured into the hole in the lug to fill it almost to the brim when the conductor is in position.

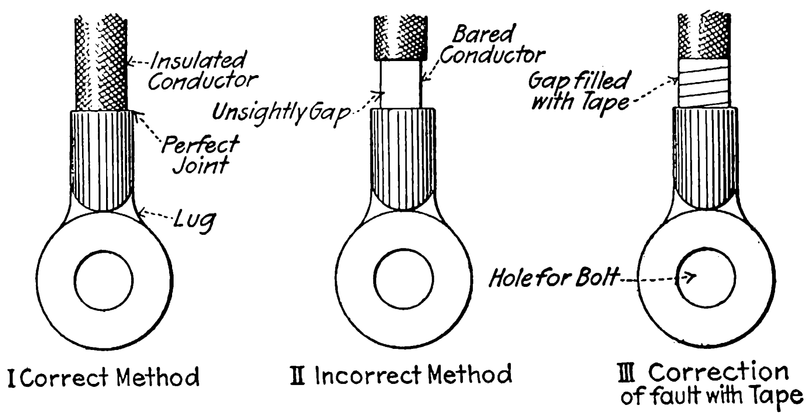


FIG. 110.—Finished connections.

If too much is poured in it will be squeezed out by the wire and will flow over the lug. It must then be removed at a sacrifice of time.

To secure proper adhesion between wire, solder and lug the temperature of all three must be above the melting-point of solder at the instant of contact. If this condition does not exist nothing more than a good friction fit of all three parts will be secured. To

secure maximum mechanical strength and electrical conductivity, it is absolutely essential that the solder be maintained at the melting-point until it has thoroughly permeated the interstices of the conductor.

The wire terminal and lug should be held in the molten solder until they acquire the temperature of the solder. To prevent adhesion of solder to the outside of the lug it should first be dipped in a light oil of high flash-point. Be careful to see that no oil is permitted to reach the inside of the lug. It will be found advisable when holding the bared ends of heavy conductors in the solder pot to wrap the insulation well with a rag previously wrung out in cold water to prevent as far as possible the melting of the insulating compound and the consequent smearing of the terminal. Any such drip will not impair the joint if properly made, though it will detract from the appearance of the finished job. (*F. P. Kenny, Electrical World.*)

Another method of soldering wires in lugs is to heat the lug with a blow-torch flame. When the lug is sufficiently hot, wire solder is fed into the hole. The solder melts and the bared conductor end is then thrust into it, as above described. However, the use of a blow torch in this way should be avoided if possible, as it blackens the exposed surfaces of the lug. A cleaning with fine sandpaper is then necessary, and it requires considerable time.

201. **A soldering flux** removes and prevents the formation of an oxide during the operation of soldering, so that the solder will flow readily and unite firmly the members to be joined. For copper wires the following solution of zinc chloride is recommended by the Underwriters, and is good:

Saturated solution of zinc chloride ..	5 parts
Alcohol	4 parts
Glycerine	1 part

Solutions made with acids should be avoided as there is usually more or less corrosion in joints made with them. The commercial soldering pastes and sticks give good satisfaction in cleaning joints to be soldered.

202. **Soldering paste or stick can be made** as follows: Melt 1 lb. of tallow and add 1 lb. of common olive oil; stir in 8 oz. of powdered rosin; let this boil up and when partially cool, add, stirring constantly, ¼ pint of water that has been saturated with powdered sal ammoniac. Stir constantly until cool. By adding more rosin to make it harder, it can be cast into sticks.

203. **In soldering commutator wires and connections** around electrical machines, an acid solution should never be used, because of the ensuing corrosive action. A good flux is an alcoholic solution of rosin.

204. **Soldering with Blow Torch and Iron.**—When soldering connections between wires smaller than No. 8 many wiremen use a blow torch for heating the joint. While a joint can be made in this way, it is much better to use a soldering copper for small wires. Where a blow torch is used the insulation on the conductors is nearly always ignited and burns with a thick smoke and blackens

any object on which it deposits. It is probable also that the excessive heat of the blow torch injures the adjacent insulation on the conductors. Furthermore, the blow torch is difficult to manipulate in restricted locations. A small alcohol torch is often satisfactorily used instead of a blow torch and is better adapted for the work, but it is probably not as good as a soldering iron.

In using a soldering copper it is heated in the flame of a blow torch. To solder the joint the hot tool is placed under and in close contact with it and wire solder is fed into the turns of the joint. After the solder has flowed over the entire surface of the joint the iron is removed and the joint is shaken to throw off surplus solder. There is no ignition of insulation and no sooty smoke. The soldering copper can be used in confined spaces where the use of a torch would be out of the question. Wires to be soldered must be scraped clean and bright before the tool is applied. Any of the commercial soldering pastes can be used as a flux.

205. **Pointers in Blow Torch Manipulation** (*W. N. Matthews & Bros. Notebook*).—Only the very best grade of gasoline (74 deg.) should be used, and it must be clean and kept in a clean can, otherwise the burner will become clogged. Never try to fill a torch from a big can. A pint or quart receptacle should be used for this purpose. If this is done, the torch can be held in one hand and filled with the other without danger of overfilling or spilling. The torch should be a little more than two-thirds full, so that there will be room for sufficient air to prevent the necessity of frequent repumping to maintain the pressure.

See that the filler plug is closed tight, to prevent the escape of air from tank. The fiber washer under the plug must be replaced when worn out. Common washing soap rubbed into threads and joints will stop all leaks. The pump should be in good working order; a few drops of lubricating oil well rubbed in will soften the pump washer. Do not turn needle valve too tight, as there is danger of enlarging the orifice of the burner. See that the burner is sufficiently heated when starting. One filling of the drip cup is generally sufficient if the flame is shielded from draft while heating the burner; if it is not, fill the cup again and light the gasoline as before. A long or yellow flame or raw gasoline shooting from the burner shows that the burner is not hot enough to properly generate gas.

Ordinarily when a gasoline torch is used, 90 per cent. of the heat is dissipated, without doing any work whatever. When performing most blow torch operations a great part of this heat may be readily saved by making a shield of sheet iron or asbestos, to direct the heat to the object to be heated.

RESISTORS

206. **A cheap and good, heavy current resistor can be made by folding wire netting** up and down over iron rods supported by insulators. (*Standard Handbook.*) Galvanized iron wire (No. 19 B. & S.) netting of 1 in. mesh and 12 in. wide has a resistance of approximately 0.005 ohm per yard and will carry 100 amp.

207. **A design for a water-cooled resistor** is shown in Fig. 111. It consists of a number of pipes fitted into couplings and supplied with brass sliding bridge pieces. With all bridge pieces at the top the resistor is practically short-circuited, but when it is desired to cut out all the resistance the terminals of the rheostat should be short-circuited through the switch. With all the bridge pieces at the bottom the resistance of the circuit becomes a maximum. The pipe connections are so made that water can be circulated through the rheostat. The connections to the water mains and outlet should be made through rubber hose. The heat capacity will depend upon the amount and temperature of the water circulated.

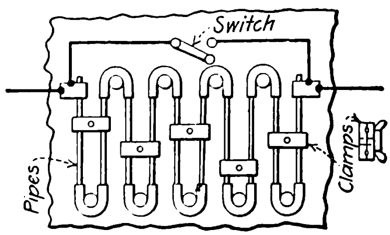


Fig. 111.—Water-cooled resistor made of pipe.

208. **Rheostats made up of galvanized-iron wire mounted on wooden frames and submerged in running water** are often used to absorb energy when making acceptance tests of large apparatus in the power house. In this case the power dissipated can be assumed as directly proportional to the surface of the resistor, and, therefore, the formula I $kd^{\frac{3}{2}}$ can be used with good results. Mr. P. M. Brown gives the following values of k as the results of extensive experiments:

Rheostat in barrel or tank, no flow of water.....	k = 540 to 700
Rheostat in flowing water (river or tail race)	k = 700 to 950
Rheostat in rapidly flowing water (river or tail race)	k = 950 to 1,250

A barrel should not be used to dissipate more than 5 kw. Values of $d^{\frac{3}{2}}$ can be taken from Table 215.

209. **Liquid rheostats are especially adapted to the absorption of large amounts of power** and are often used as an artificial load in testing dynamos or as starting rheostats for large motors starting under load. The adjustment is perfectly continuous, but unless there is a provision for short-circuiting the electrodes outside the solution it is impossible to cut out the resistance entirely. The material of which the electrodes are made is not important so long as it is a good conductor and is not attacked by the liquid. Lead or carbon plates are used with sulphuric acid, copper with copper sulphate and iron in most other cases. The current density should not exceed 1 amp. per square inch.

210. **The solution in a liquid rheostat** depends upon the voltage and quantity necessary to radiate the heat. Pure water is seldom used for pressures under 1,000 volts. For voltages below this sulphuric acid or some salt is added to the water to increase its conductivity. Fig. 112 shows the relative conductivity of various solutions expressed in inches between the plates with a current density of 1 amp. per square inch. Ordinary water gives a drop from 2,500 to 3,000 volts per inch gap at this current density.

211. **The radiation capacity of a liquid rheostat** depends upon the volume of the solution used and not upon the area of the surface.

It is also affected by the conductivity of the material of which the tank is made; the amount of radiating surface of the tank; the temperature, pressure and dampness of the surrounding air; and the counter e.m.f. generated by chemical action (at low pressures a large proportion of the power may be absorbed chemically without the evolution of heat). Fig. 113 is constructed from experiments made by H. W. W. Dix and shows the allowable watts per cubic inch for different values of temperature rise.

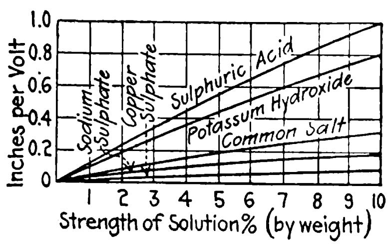


FIG. 112.—Curves showing conductivity of various solutions.

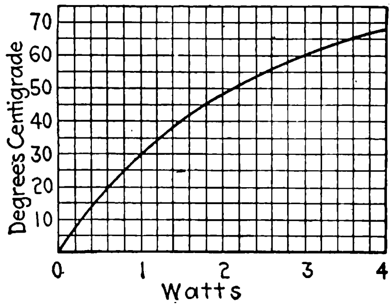


FIG. 113.—Allowable watts per cubic inch for a liquid rheostat.

As a general rule take 400 to 800 cu. in. of solution per horsepower absorbed continuously. For motors, about 20 cu. in. per horse-power capacity should be allowed for starting and 60 cu. in. per horse-power for running.

212. **A good design for a liquid rheostat,** which can be easily constructed, is shown in Fig. 114. It is arranged so as to short-cir-

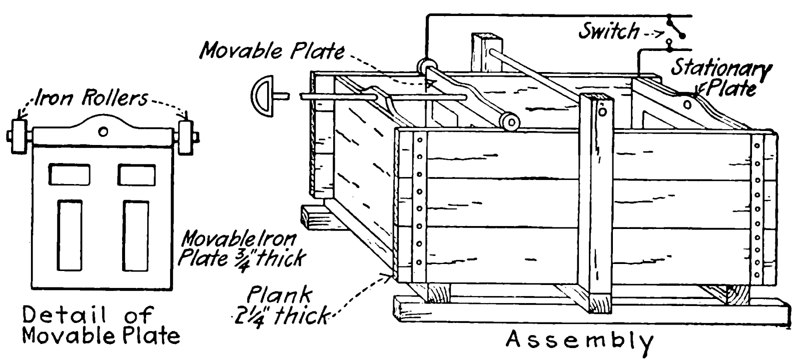


FIG. 114.—Water rheostat.

cuit the electrodes with the switch when all resistance is out. The size of the tank is determined by the size of the electrodes (roughly the area of the electrodes in square inches equals number of amperes) and the volume of the liquid necessary to radiate the heat liberated by the absorption of the given amount of power (Fig. 112). Knowing the size of the tank and the voltage, the solution and materials for the electrodes and tank can easily be chosen.

213. Water rheostats can be worked at higher densities than those given in Fig. 114 by allowing cool water to circulate through the tank. It will require $\frac{86.5}{t}$ kg. or $\frac{190}{t}$ lb. of water per hour to dissipate the heat liberated by the absorption of 1 kw. with a temperature rise of t deg. cent. This formula also applies to the cooling of metallic resistors submerged in running water.

214. Where high voltage is used the water must be conducted to and from the tank in rubber hose. For potentials up to 2,500 volts a length of 15 to 20 ft. is sufficient to prevent grounding, providing the diameter does not exceed 1 in. For larger diameters a correspondingly longer hose must be used.

215. Values for Galvanized-iron Wire of $d^{\frac{3}{2}}$ in $I = kd^{\frac{3}{2}}$.
(*Standard Handbook*)

Size B. & S.	Solid		Stranded		Size cir. mils.	Stranded	
	d-inch	$d^{\frac{3}{2}}$	d-inch	$d^{\frac{3}{2}}$		d-inch	$d^{\frac{3}{2}}$
20	0.0320	0.00571	....	....	250,000	0.575	0.437
18	0.0403	0.00809	....	....	300,000	0.634	0.505
16	0.0508	0.01145	....	....	350,000	0.682	0.563
14	0.0641	0.01622	0.073	0.0197	400,000	0.728	0.621
12	0.0808	0.02298	0.092	0.0278	450,000	0.777	0.685
10	0.102	0.03254	0.116	0.0394	500,000	0.815	0.736
8	0.128	0.04620	0.145	0.0555	550,000	0.855	0.791
6	0.162	0.06520	0.184	0.0788	600,000	0.893	0.844
5	0.181	0.07760	0.206	0.0940	650,000	0.930	0.896
4	0.204	0.09240	0.232	0.112	700,000	0.965	0.947
3	0.229	0.1098	0.260	0.133	750,000	0.999	0.998
2	0.258	0.1306	0.292	0.158	800,000	1.031	1.047
1	0.289	0.1555	0.332	0.911	900,000	1.094	1.145
0	0.325	0.1852	0.375	0.230	1,000,000	1.153	1.238
00	0.365	0.2203	0.419	0.271	1,250,000	1.290	1.465
000	0.410	0.2620	0.470	0.322	1,500,000	1.412	1.679
0000	0.460	0.3120	0.528	0.384	1,750,000	1.526	1.885
....	....	....	....	....	2,000,000	1.631	2.083

NOTE.—Formula $I = kd^{\frac{3}{2}}$ is used in calculation of wire for rheostats with forced cooling (208).

CIRCUITS AND ELECTRICAL DISTRIBUTION

216. A series circuit is one in which all components are connected in tandem as in Figs. 115 and 116. The current at every point of a series circuit is the same. Series circuits find their most important commercial application in series arc and incandescent lighting. They are seldom if ever used in this country for the transmission of power.

217. Multiple, parallel or shunt circuits are those in which the components are so arranged that the current divides between them (Figs. 116A and 117). Commercially, the distinction between

multiple and series circuits is that, in series lighting circuits, the current is maintained constant and the generated e.m.f. varies with the load, whereas, with multiple circuits, the current through the

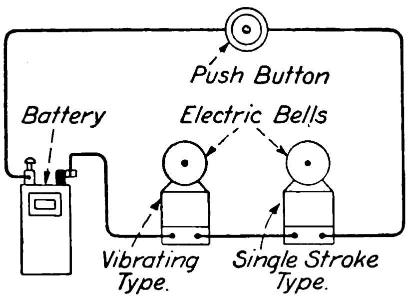


FIG. 115.—Series electric-bell circuit.

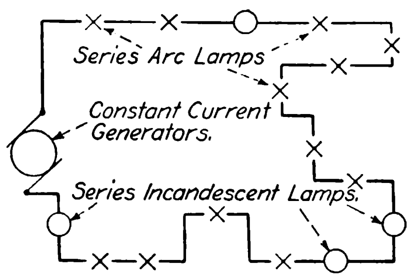


FIG. 116.—Series street-lighting circuit.

generator varies with the load and the generator e.m.f. is maintained practically constant.

218. Adding receivers in parallel on multiple circuits is really

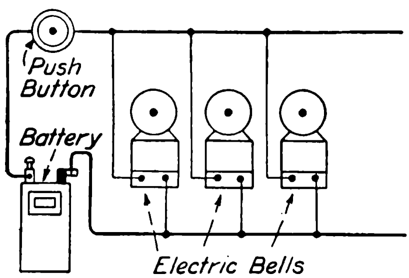


FIG. 116A.—Electric bells in parallel.

equivalent to increasing the cross-section of the imaginary conductor formed by all the receivers in parallel between the + and the − sides of the circuit.

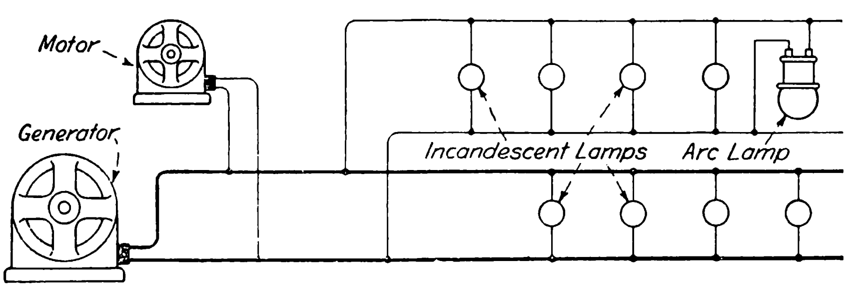


FIG. 117.—A multiple circuit for light and power.

219. The distribution of current in a multiple circuit is shown in Fig. 118. Motors, heating devices or other equipment requiring electricity for their operation could be substituted for the incan-

descent lamps if the proper current values were substituted for those shown. Note that the current in the main conductors decreases toward the end of the run and that the current supplied by the source—the generator—is equal to the sum of the currents

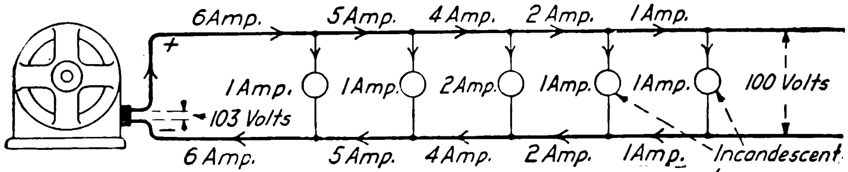


FIG. 118.—Multiple circuit currents.

required by all of the components. The voltage at the end of the run is less than that at the generator.

220. A multiple-series or parallel-series circuit consists of a number of minor circuits in series with each other and with several of

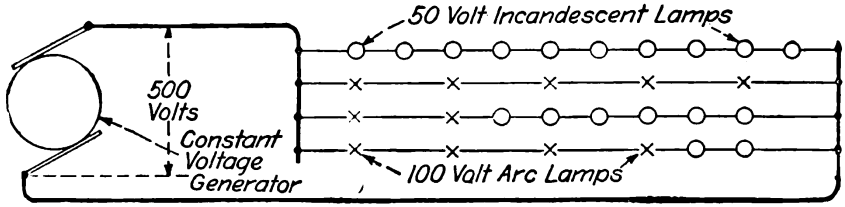


FIG. 119.—A parallel-series or multiple-series circuit.

these series then connected in parallel, as shown in Fig. 119. Arc lamps designed for such connection and incandescent lamps are sometimes arranged in this way. For example, 5 arc lamps each requiring 100 volts or 10 incandescent lamps requiring 50 volts

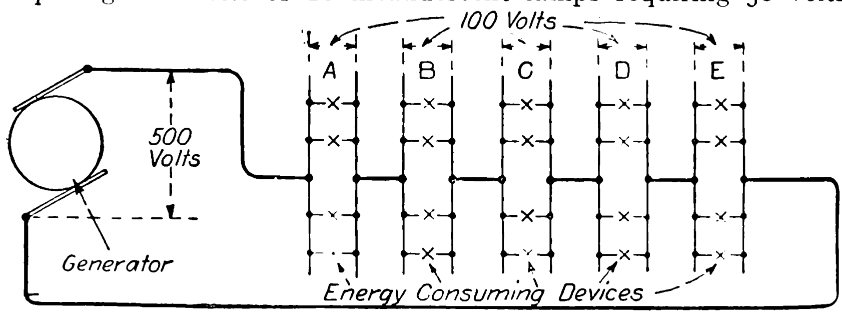


FIG. 120.—A series-parallel or series-multiple circuit.

are respectively connected in series and then these series groups are connected across a 500-volt railway circuit.

221. A series-multiple or series-parallel circuit is one wherein a number of minor circuits are first connected in parallel, and then several of the parallel-connected minor circuits are connected in series across a source of e.m.f. as in Fig. 120. This method of connection is seldom used. (There appears to be a difference of opinion as to what constitutes a "*series-multiple*" and what a "*multiple-series*" circuit. The definitions of Pars. **220** and **221** are in accordance with the practice of the General Electric and Westinghouse companies.)

222. A divided circuit (Fig. 121) is really one form of a multiple or parallel circuit. The distinction between the two sorts appears to be that, as ordinarily used, the term "divided" refers to an isolated group of a few conductors in parallel rather than to a group of a large number of conductors in parallel.

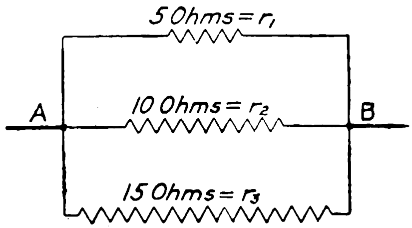


FIG. 121.—A divided circuit.

223. The joint resistance of a number of conductors in parallel can be computed with the following formula. There should be as many terms in the denominator of the formula as there are conductors in parallel:

$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4}}, \text{ etc.}$$

Example—What is the joint resistance of the conductors in the divided circuit shown in Fig. 121? In other words, what is the resistance from *A* to *B*? *Solution.*—Substitute in the formula:

$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}} = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{15}} = \frac{1}{\frac{6}{30} + \frac{3}{30} + \frac{2}{30}} = \frac{1}{\frac{11}{30}} = 1 \times \frac{30}{11} = 2.73 \text{ ohms.}$$

224. A feeder (or feeder circuit) is (Figs. 122 to 124) a set of conductors in a distributing system extending from the original source of energy in the installation to a distributing center and having nothing connected to it between the source and the center. The source may be a generating or a sub-station or, in the case of building or house wiring a connection to the service conductors from the street. (See Figs. 122, 123 and 124.)

225. A main. (Figs. 122 to 124.) There are really two rather distinct classes of mains thus:

(1) A main is an extension of a feeder extending from one distribution center to another distribution center having nothing connected to it between the two distribution centers. Frequently a main of this character is called a *sub-feeder.* (Fig. 122.)

(2) A main is any supply circuit to which other circuits (sub-mains or branches) connect *through automatic cut-outs*—fuses or circuit breakers—at different points along its length. Where a main is supplied by a feeder the main is usually of smaller wire than the feeder which serves it. An energy-consuming device is never connected directly to a main, a cut-out always being interposed between the device and the main.

225A. A sub-main (Fig. 122) is a subsidiary main, fed through a cut-out from a main or another sub-main, to which branches are connected through cut-outs. A sub-main is usually of smaller wire than the main or other sub-main which serves it. Ordinarily sub-mains are referred to as merely "mains." The term sub-main has not been used very extensively.

226. **A branch or branch circuit** (Fig. 122) is a set of **conductors** (feeding, through an automatic cut-out, from a distribution center, main or sub-main) to which one or more energy-consuming devices are connected directly—without the interposition of cutouts. The only cut-out associated with a branch is that through which the branch is fed at the main, sub-main or distribution center.

227. **A tap or tap circuit** (Fig. 122) is a circuit, serving a single energy-consuming device, connecting directly to a branch without the interposition of a cut-out.

228. **A distributing or distribution center** is an arrangement or group of fittings whereby two or more minor circuits are connected at a common point to another, larger circuit. A **panel box** is one form of a distribution center. (See Figs. 122 to 124.)

229. **A service** (or a service connection) is a set of conductors constituting an underground or an overhead connection between conductors (a **main** belonging to a public service corporation) in a thoroughfare and those of an interior or isolated wiring system. A "service" serves the wiring system with energy.

230. **A loop circuit** (see Fig. 125) is one wherein all receivers,

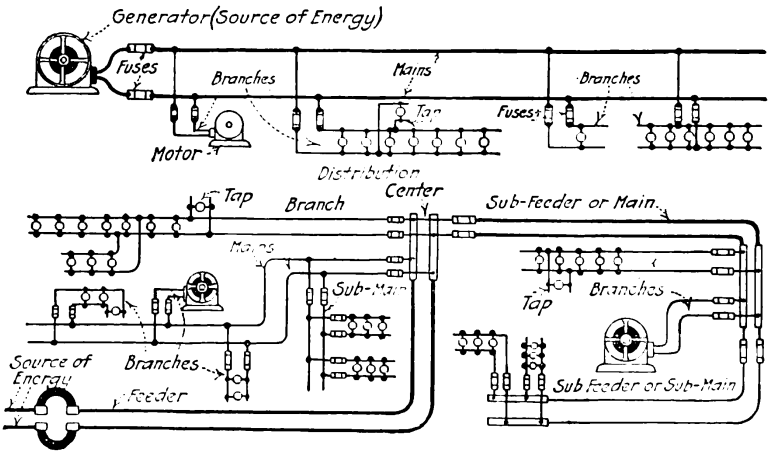


FIG. 122.—Diagram illustrating circuit nomenclature.

lamps or motors for example, are at the same electrical distance from the source of electricity. By tracing paths from one terminal back to the other through any receiver it will be found that the length of line is the same in every case. It is sometimes supposed (*Crocker's Electric Lighting*) that this arrangement of conductors must give the same pressure at all of the receivers since the sum of the distances of each receiver from the feeding points measured on the mains is constant. Actually the middle receiver (see Fig. 125) will receive a lower voltage than those at the ends as shown in the diagram. This is due to the fact that the middle receivers are supplied through the portions of the main conductors which carry heavy currents and in which the drop is greatest. For example, the drop on the mains in the case of the central receiver

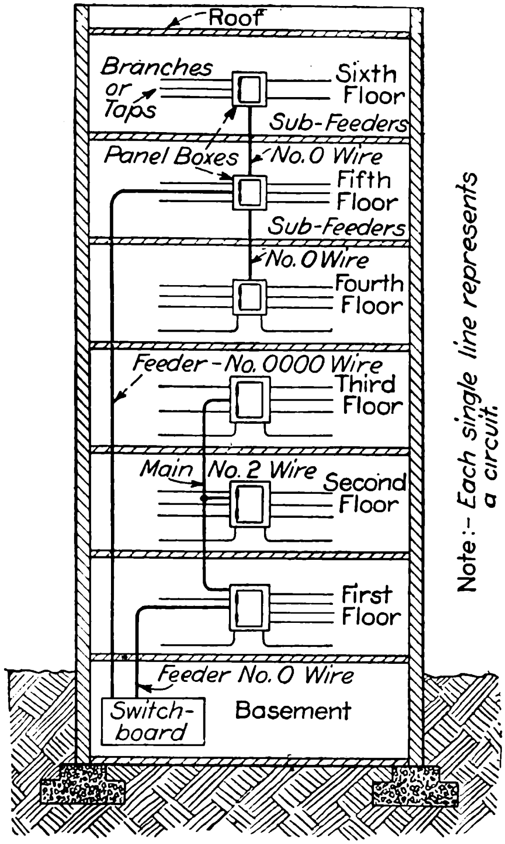


FIG. 123.—Examples of feeders, mains and branches.

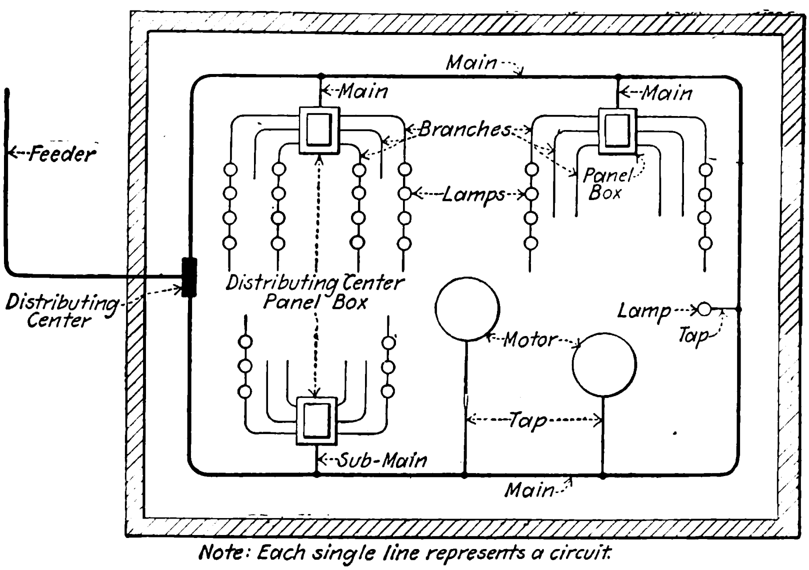


FIG. 124.—Diagram showing "closed-loop-main."

is, $2+1.5+1.5+2=7$ volts, while for the end receiver it is but $2+1.5+1+0.5=5$ volts.

Loop circuits are seldom used in modern installations. They provide close voltage regulation but more conducting material is required than for some of the other forms of circuits which provide sufficiently good results.

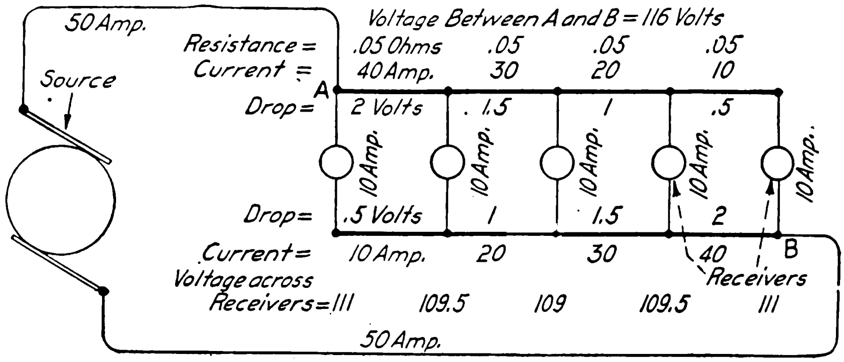


FIG. 125.—Loop circuit.

231. A tree circuit (Fig. 126) is so called because its main conductors resemble a tree trunk and the branch conductors limbs.

Tree circuits of considerable length and feeding many receivers are usually undesirable and uneconomical because it is impossible to maintain a reasonable voltage regulation on them without using very large main conductors. Short tree circuits consisting of mains and branches are often and advantageously used in both interior and out-of-door distribution.

232. Main-and-feeder circuits are widely used in modern electrical distributions. This is not only because the feeder and main method is, for a given voltage regulation at the receivers, the least costly to install but also because it is the most reliable, in that it divides the load into sections so that short-circuits or trouble in one section is not apt to affect the rest of the load. This method of distribution is usually adopted by the central station companies in the construction of their out-of-door wire plants to distribute electricity to their subscribers. Practically the same system, on a smaller scale, is nearly always used within buildings to distribute electricity to lighting equipment and motors. (See Figs. 122 to 124.) The feeder in an interior feeder and main system may connect to the service of an out-of-door feeder and main system.

233. A ring circuit (Fig. 124) is one wherein a main (or possibly a branch) forms a closed ring. It is usually a special case of a feeder-and-main circuit. In out-of-door distributions ring mains are sometimes carried around a city block or around a certain district and branch mains or services are fed by the ring main. One feeder or several may serve a ring main each connecting at a different point. In interior electrical distributions, ring mains are seldom

used except in industrial plants, but for this service they can often be applied to advantage.

234. **The three-wire system is used because it saves copper.** (See Fig. 127.) Incandescent lamps for about 100 volts are more economical than those for higher or lower voltages. A system of any consequence operating at 110 volts would require very large conductors to maintain the line drop within reasonable limits. With the three-wire system, a low voltage, say 110, is impressed on the receivers while one twice as great, say 220, is used for transmission. Since the weight of conductors for a given loss varies inversely as the square of the voltage (see **242**) it is evident that a considerable saving is possible with the three-wire system. In this country the three-wire system is of most importance as applied to 110–220 volt lighting systems.

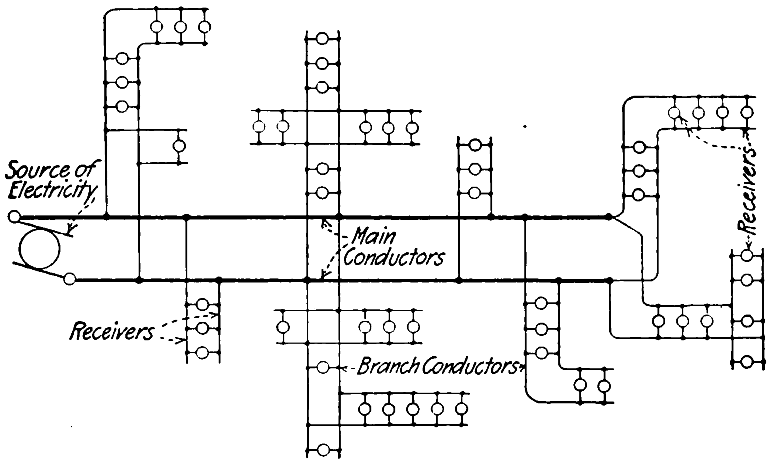


Fig. 126.—Tree circuit.

235. **The principle of the three-wire system is illustrated** in Fig. 127. Incandescent lamps for 110 volts could be connected two in series across 220 volts as shown at *I* and while each lamp would operate at 110 volts, the energy to the group would be transmitted at 220 volts and the outside conductor could, with equal loss, be one-fourth the size that would be necessary if the energy was transmitted at 110 volts. This arrangement (Fig. 127, *I*) while it would operate, is not commercially feasible because each lamp of each pair of lamps in series must be of the same size and if one lamp goes out its partner is also extinguished. These disadvantages might be partially corrected by running a third wire as at Fig. 127, *II*. Then one lamp might be turned off and the others would burn and a single lamp might be added to either side of the system between the third wire and either of the outside wires. But unless the total resistance of all of the lamps connected to one side was practically equal to that of all of the lamps connected to the other side, the voltage across one side would be higher than that across the other. On the high side the lamps

would burn bright and on the low side dim. Obviously, it is not feasible in practice to so arrange or "balance" the sides that they will have the same resistance. Hence some other method must be used in practicable three-wire systems whereby the electricity will be transmitted at, say, 220 volts and the pressure across the lamps will be, say, 110 volts.

236. **Commercial three-wire systems** consist (Fig. 127, *III* and *IV*) of two outer conductors, having (for lighting installations) a pressure of 220 volts impressed across them and a neutral wire so connected to sources of voltage that the pressure between it and either of the outside wires is 110 volts. In Fig. 127, *III*, generators are the sources of voltage. The neutral wire joins at the

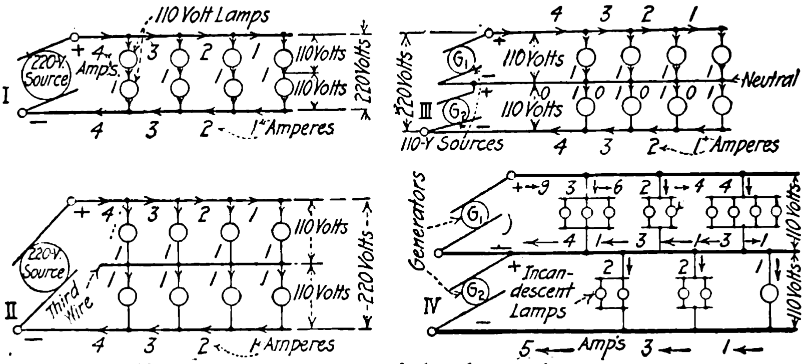


FIG. 127.—Elements of the three-wire system.

point where the generators are connected together. When the system is perfectly balanced, the neutral wire carries no current and the system is in effect a 220-volt system. Perfect balance seldom obtains in practice. When the balance is not perfect, the neutral wire conveys a current equal to the difference between the current taken by one side and that taken by the other side. Note from Fig. 127, *IV*, that the current in different parts of the neutral wire may be different and that it is not necessarily in the same direction in all parts of the neutral wire. Each incandescent lamp in Fig. 127, *IV*, is assumed to take 1 amp. and the small figures indicate the currents in different parts of the circuit.

237. **The Size of the Neutral Wire of Three-wire Systems.**—Where the balance is and always will be perfect no neutral wire is necessary. In out-of-door distribution systems the neutral is often one-half the size of the outer wires. For interior wiring, the neutral is frequently made the same size as the outside wires. However, a neutral conductor having two-thirds—or even one-half—the cross-sectional area of each of the outers will usually be satisfactory if it is protected in accordance with *Code* requirements. Some engineers specify thus: Where the outers are No. 6 or smaller, the neutral shall have the same area as each of the outers and where the outers are larger than No. 6 the neutral shall have two-thirds the area of each of the outers.

238. **The amount of unbalance that may come on a three-wire system** depends on local conditions. In ordinary three-wire lighting systems the unbalanced load seldom exceeds 10 per cent. of the total load. Probably 5 per cent. is a fair average for a well-

laid-out system. Balancer sets for interior three-wire systems are frequently specified of sufficient capacity to take care of a 10 per cent. unbalance. Sometimes the unbalance on a poorly laid out system may be 20, 30 per cent. or even more.

239. Application of Alternating Current and of Direct Current for Distribution.—The following suggestions are general and cannot be expected to apply to every special case. Where electricity is to be distributed for lighting only and not at a greater distance than about a mile from the generating station, direct current will probably be most satisfactory and economical. If many adjustable speed motors are to be served by a distribution, direct current should be used at the motors even if it is necessary to convert alternating into direct current, at the using point, with a motor generator or rotary converter. There is no satisfactory alternating current, adjustable speed motor that has the general characteristics of the direct-current shunt or compound wound motor.

Where electricity is to be distributed to points more than a mile distant from the station, alternating current will usually be most economical and satisfactory. It may be generated at a reasonably high voltage and transmitted to the points where it is to be used at that voltage and there "stepped down" with transformers to the voltage required by the receivers. Transmitting at a high voltage makes possible the use of small feeder conductors. Where many constant-speed motors are to be used, polyphase alternating current is always preferable for either short or long distribution distances because polyphase constant-speed motors are simpler and more reliable than direct current. Furthermore, alternating-current motors can be operated on higher voltages than can direct current, so it is not necessary to step down for them unless the voltage of the generator is quite high. Two-wire (single-phase) electric lighting can always be arranged from single-phase or polyphase alternating-current circuits.

Alternating current is always used where it is necessary to transform from one voltage to another without the use of moving apparatus and offers a very flexible system in this respect. But where transformers are used there are slight losses in them even when they are not loaded. An alternating-current system also has the disadvantages that its inherent voltage regulation and its efficiency are not so good as those of a direct-current system. This is particularly true if much inductive equipment, that containing coils wound on iron such as motors and arc lamps, is connected to the circuits. Despite these disadvantages experience has shown that alternating is preferable to direct current for the applications outlined above. Polyphase constant-speed motors are preferable to direct-current constant-speed motors because they are simpler, in that they have no commutator and they cost less to maintain than do direct-current motors. Direct current is nearly always used in office buildings served by isolated plants because such loads are mainly lighting.

240. Selection of a Frequency.—There are two frequencies now standard in this country, 25 cycles and 60 cycles. All other

things being equal, 25 cycles would seem at first sight preferable because there is less inductive effect with it than with a higher frequency. It therefore follows that the inherent voltage regulation of a 25-cycle system is better than that of a 60-cycle system and also that the 25-cycle system is a trifle more efficient. For transmission distances of less than a few miles neither of these factors is of much consequence one way or the other. Alternating current at 25 cycles is not particularly well adapted for electric lighting because arc lamps do not operate well on it and, under some conditions, with certain generator waves, a flickering due to 25-cycle current alternations is visible in incandescent lamps. With frequencies lower than 25 the flickering is quite perceptible, while with 60 cycles no flickering is noticeable. However, some large lighting systems are successfully operated at 25 cycles. The advent of metallic filament lamps of high candle-power renders the matter of operation of multiple arc lamps of little importance and series arc lamps are now usually operated on direct current.

Several years ago a frequency of 25 cycles was often considered necessary for the operation of rotary converters but modern converters operate as well on 60 cycles as on 25.

It is often wise for an isolated plant to adopt the frequency of the local central station so that, in emergencies, energy or apparatus can be interchanged. Transformers and most other apparatus, except very slow speed motors, is as cheap or cheaper for 60 cycles as for 25 and the delivery on 60-cycle apparatus is better. A great proportion, probably over 85 per cent., of the equipment sold in this country is for 60 cycles and it is probable that the average isolated plant, central station or industrial plant which supplies electricity for light or power or for both should adopt a frequency of 60 cycles. However, where the power load is important and very slow speed motors must be used 25 cycles is adopted as it is not feasible to economically build 60-cycle motors for very slow speeds. For example, steel mills and cement plants often adopt 25 cycles.

241. Selection of a Voltage for a Distribution System.—The standard voltages for which American manufacturers build electrical apparatus are 110, 220, 440, 550, 1,100, 2,200 and higher ones, the treatment of which is not within the scope of this book. These are nominal voltages and it is seldom that apparatus is operated at exactly any one of them. It may be operated at some one voltage within a range extending from, possibly, 5 per cent. below to 5 per cent. above the nominal voltage.

Incandescent lamps for 220 volts, in the 50- to 60-watt sizes, are 10 to 15 per cent. less efficient and cost more than do corresponding 110-volt lamps. This is an inherent condition due to the relatively great length and smaller diameter of the 220-volt filament and it cannot be corrected. Steinmetz says: "The 220-volt lamp has no right to existence." It follows that a nominal voltage of 110 (an actual voltage of something between 105 and 120 volts) should be used at the terminals of incandescent lamps where feasible. Sometimes (Fig. 128) it is desirable to use 220-volt lamps where the load is largely a 220-volt motor load. In such a

case the use of 220-volt lamps may be justified because of the simplicity of the method.

Branches serving incandescent lamps (Fig. 128, *II*) must always be two-wire and should be 110-volt, but the mains, even in residence wiring, are often, and profitably, three-wire because of the economy in copper of the three-wire system.

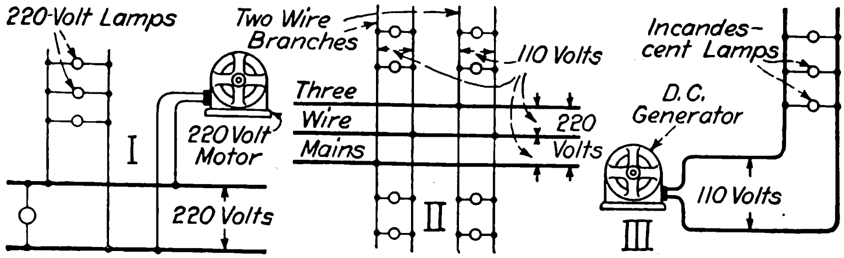


FIG. 128.—Methods of connection.

For incandescent lighting alone, in a town, industrial plant or building, for distribution distances not exceeding about 1,000 ft. a two-wire, direct-current circuit (Fig. 128, *III*) with a nominal voltage of 110 can be used with fair satisfaction. But a three-wire circuit having 220 volts across the outside wires will usually cost

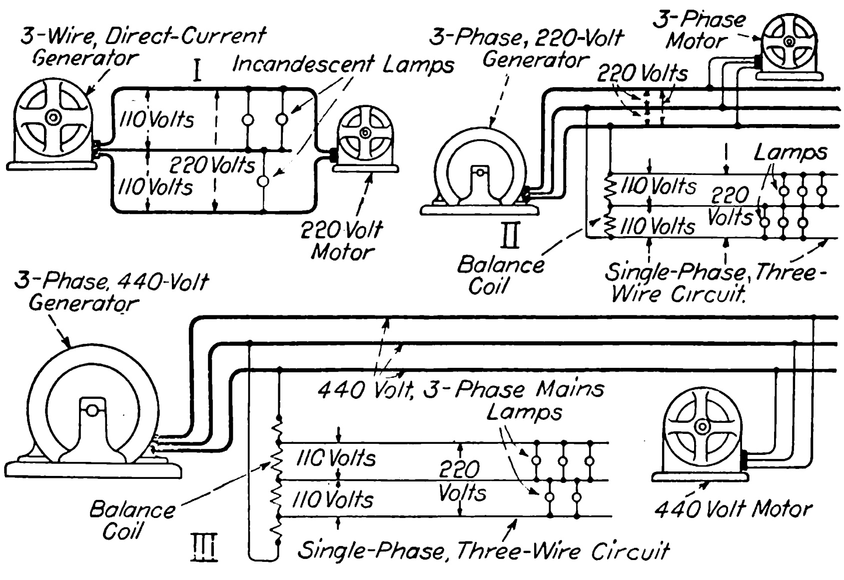


FIG. 129.—Distribution circuits.

less to install and it can be used with fair economy for distances up to possibly a mile. If the load is almost entirely lighting or adjustable speed motors, the distribution (Fig. 129, *I*) should be direct-current 110–220 volt, three-wire, and motors should be operated at 220 volts. But if there is a considerable constant-speed

motor load, a 220-volt, three-phase distribution (Fig. 129, *II*) should, probably, be used. The motors can be operated three-

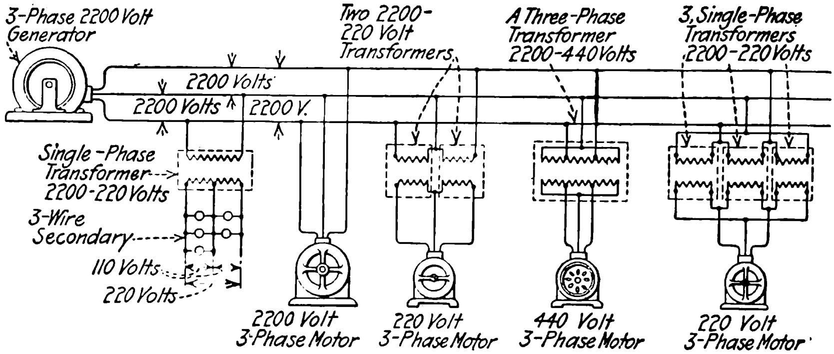
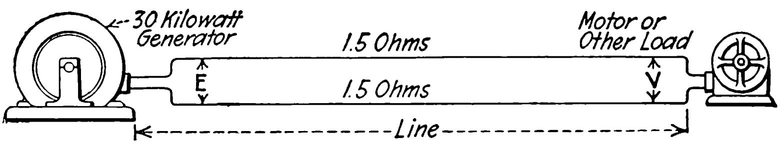


FIG. 130.—A 2200-volt distribution.

phase, and then three-wire, single-phase, 110–220-volt lighting circuits can be arranged from one or all of the phases with balance coils. (See Fig. 129, *II*.)



Note: This table is strictly correct for direct-current and is very nearly correct for alternating-current

30 Kilowatts Generated at E Volts
(Timbie's Elements of Electricity)

Volts E	Amperes I	Line Drop in Volts R=3 Ohms IR	Line Loss in Watts I^2R	Volts Left for Motor V	Watts Transmitted to Motor	Efficiency of Line Per Cent
100	300	900	Impossible Case		——	——
200	150	450	Impossible Case		——	——
300	100	300	30,000	0	0	0
400	75	225	16,875	175	13,125	43.8
500	60	180	10,800	320	19,200	63.3
600	50	150	7,500	450	22,500	75.
800	37.5	112.5	4,219	687.5	25,780	86.
1000	30	90	2,700	910	27,300	91.
1200	25	75	1,875	1,125	28,125	93.8
1500	20	60	1,200	1,440	28,800	96.
2000	15	45	675	1,955	29,325	97.8
3000	10	30	300	2,970	29,700	99.
5000	6	18	108	4,982	29,964	99.8
10,000	3	9	27	9,991	29,973	99.9

FIG. 131.—Illustrating relation of voltage to efficiency of transmission.

Either a 440- or a 550-volt, three-phase, distribution using (Fig. 129, *III*) 440- or 550-volt motors might profitably be used instead of the 220-volt and a saving of about three-fourths the

copper would result. Balance coils could be used to provide 110–220-volt, three-wire, lighting circuits. However, a voltage exceeding 300 is quite apt to kill a man that crosses it, while persons are very seldom killed on the voltages lower than 300. So, as a rule, 440 volts or greater should not be installed in any plant where the electrical apparatus cannot have expert supervision. Yet 440 or 550 volts is low enough that motors can be conveniently operated at those pressures and in practice the insulation used on

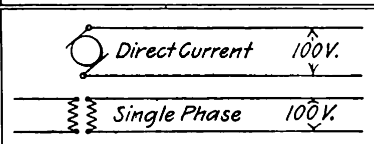
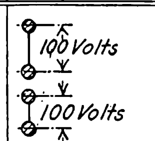
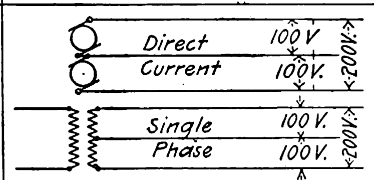
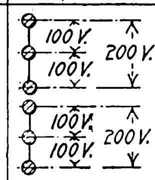
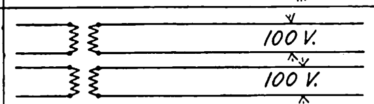
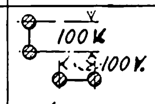
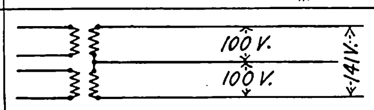
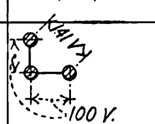
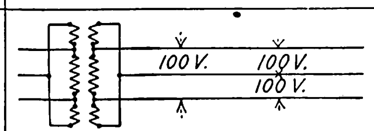
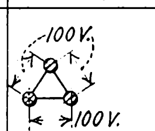
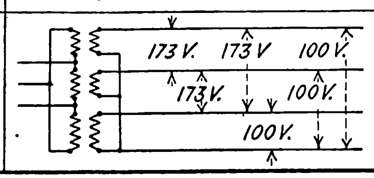
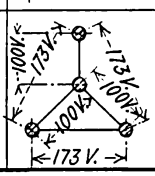
SYSTEM	CONNECTIONS	DIAGRAM SHOWING PHASE RELATIONS	RELATIVE WEIGHTS OF COPPER
Direct Current or Single Phase 2 Wire			100.0
Direct Current or Single Phase 3 Wire			With neutral same size as outers = 37.5 With neutral ½ size of outers = 31.3 With neutral ⅓ size of outers = 29.2
Two Phase 4 Wire			100.0
Two Phase 3 Wire			With neutral same size as outers = 75.0 With neutral 1.41 times as large as outers 72.9
Three Phase 3 Wire			75.00
Three Phase 4 Wire			With neutral same size as outers = 33.3 With neutral ½ size of outers 29.2

FIG. 132.—Copper economies of different distribution systems.

them is the same as for 220-volt machines. Voltages of 440 or 550 find their widest applications in industrial plants and are seldom used in central-station distributions. Direct-current voltages of 400 to 550 are now seldom used except in street railway work.

A voltage of 1,000 is practically never used in commercial work in this country except for railways.

For central stations or industrial plants distributing to distances

up to a few miles from the station, a nominal alternating current voltage of 2,200 is often adopted. Higher voltages, the treatment of which is not within the scope of this book, are also frequently used. (See Fig. 130.) The generators are three-phase in modern installations and each or one of the phases is used for single-phase lighting. Power service is supplied by all three phases. Transformers stepping down from 2,200, single-phase, to 110 volts single-phase or to 110-220 volts, single-phase, three-wire, are used for lighting. Three-phase transformers, stepping from 2,200 to 220, 440 or 550 volts are used for three-phase constant-speed motors or, in special cases, 2,200-volt motors are used. If adjustable-speed motors are required, a motor generator set can be installed which will deliver direct current at 220 volts.

242. A high distribution voltage is desirable from the standpoint of cost of line conductors because: *The power lost in a given line, transmitting a given watts load, varies inversely as the square of the impressed voltage.* It follows that: *The weight of a conductor for transmitting a given watts load with a given power loss is inversely proportional to the square of the voltage.* If the voltage is doubled, only one-fourth the copper will be required to transmit the power with the same energy loss in the line. Requirements of safety and utility compel the use of relatively low voltages for ordinary electrical distribution.

Example.—Fig. 131 illustrates the economy of high line voltages by giving values for the transmission of a certain amount of power at different voltages.

243. Relative Weights of Copper Conductors Required for Different Systems of Distribution.—The values given in Fig. 132 are true ones assuming for all systems: equal voltages on the lamps or other receivers, equal amounts of power transmitted, equal line losses and balanced circuits. The weight of the conductors of a two-wire, direct-current circuit is assumed, for convenience, to be 100 per cent. For the derivation of the values see *Crocker's Electric Lighting*, Vol. II.

BATTERIES

244. The Theory of the Electric Battery (*Standard Handbook*).—When two different metals come in contact with each other there is generated an e.m.f. the value of which depends upon the kind of metal, the character of the contact surfaces, the medium in which the contact takes place, the conditions existing in the medium, etc.

If a circuit made up of various substances and including no source of energy is closed on itself the various contact e.m.fs. will just compensate and the resultant e.m.f. of the circuit will be zero. However, if the circuit includes a source of energy as heat (thermocouple), or chemical reaction, an unbalance of e.m.f. will be produced and a current established, this current tending to reduce the e.m.f. of the source and restore the static balance of the system. **Polarization** is the action of the current in reducing the e.m.f. of the cell and it is overcome by the use of certain substances called depolarizers.

245. The materials consumed in a battery represent a given quantity of energy. Since the internal e.m.f. is a constant, the total electrical energy output of the chemical reaction is directly proportional to the quantity of electricity produced.

246. The e.m.f. of a given cell is the contact e.m.f. and is therefore independent of the dimensions of the battery. The energy and power of the battery, however, are directly affected by the dimensions. For a given battery the energy stands in a direct ratio to the weight of active material. The power for a given number of cells in series (given e.m.f.) is determined by the area of the plates. The e.m.f., of course, depends only on the number of cells in series.

247. The standard Daniell cell has an e.m.f. which is practically 1 volt when delivering a constant current. There are many forms of Daniell cell; each of which is particularly adapted to certain service, but all having very nearly the same e.m.f. (1.07+volts). The e.m.f. is not changed appreciably by the degree of concentration of the solutions; by the temperature; by the resistance; by the purity of the zinc or copper, etc. In short, it makes a very good rough and ready standard.

A very good model is that used by the British Post-office. The jar is made with two compartments; one containing the porous cup immersed in water, in which are placed a copper plate and crystals of copper sulphate. The other compartment contains the zinc plate and the 50 per cent. saturated solution of zinc sulphate. The zinc plate is fastened so as to be just clear of the solution, and a pencil of zinc is placed in the bottom. When in use, the porous cup is placed in the second compartment, thus raising the level of the zinc solution so as to immerse the zinc. Under working conditions the e.m.f. is about 1.07 volt; when new it is about 1.079 volts.

248. The gravity type cell, which is used in telegraph work, is suitable for closed-circuit work, but should not be used for applications where it is liable to stand for a long time on open-circuit.

249. In setting up the gravity cell place the copper electrode (−) in the bottom of the jar and pour in about 3 lb. of copper sulphate crystals. Next place the zinc electrode (+) and fill with water to cover the zinc; to the water add a tablespoonful of sulphuric acid. Cover the electrolyte with a layer of pure mineral oil, which should be free from naphtha or acid and have a flash point above 400 deg. fahr. If the oil is not used the creeping can be stopped by dipping the edge of the jar in hot paraffin. When the cell is thus set up it should be short-circuited for a day or two to form zinc sulphate which will protect the zinc electrode; this preliminary run also reduces the internal resistance. The temperature of the cell should be kept above 70 deg. fahr., since the resistance increases very fast with a decrease in temperature.

The internal resistance of the gravity cell is ordinarily from 2 to 3 ohms. A blue color in the bottom of the cell denotes a good condition, but a brown color shows that the zinc is deteriorating. When renewing the copper sulphate it is best to empty the cell and set it up with a completely new electrolyte. The blue line,

which marks the boundary between the copper sulphate and the zinc sulphate, should stand about half way between the electrodes. If it comes too close to the zinc, some of the copper sulphate can be siphoned out or the cell can be short-circuited so as to produce more zinc sulphate. If the blue line goes too low some water and crystals of copper sulphate should be added.

250. **The Fuller cell** is well adapted to telephone work or any intermittent work. It can stand on open-circuit for several months at a time without any appreciable deterioration.

251. **The Fuller cell is set up** as follows: Mix the electrolyte by adding 6 oz. of potassium bichromate and 17 oz. of sulphuric acid to 56 oz. of soft water; pour this mixture into the glass jar. Into the porous cup put one teaspoonful of mercury and two teaspoonfuls of salt; place the cup and zinc electrode in the glass jar and fill to within 2 in. of the top with soft water. Put on the cover, insert the carbon electrode, and the cell is ready for use.

The color of the solution is orange when in working order. The resistance varies from 0.5 to 4 ohms depending upon the condition and dimensions of the porous cup and upon the concentration of the solution.

252. **The Edison-Lalande or Edison cell** is suitable for either open or closed-circuit work. The mechanical construction of this cell is especially good. The positive pole is a plate of compressed oxide of copper, the surfaces of which are reduced to metallic copper to improve the conductivity. This form of plate also acts as a depolarizer. The negative pole is of pure zinc amalgamated throughout by adding mercury when the casting is made. The electrolyte is a solution of caustic soda. The top of the solution is covered with a heavy mineral oil to prevent the solution from evaporating.

These cells have an initial e.m.f. of 0.95 volt, which drops to 0.70 volt when the circuit is closed. The internal resistance is very low, varying from 0.020 to 0.089 ohm, depending upon the type of cell. The Edison Manufacturing Co. have kindly submitted the following data:

Continuous capacity, amp......	1.5	2.5	4.0	6.0	7.0
Max. capacity, amp...........	7.49	9.53	15.51	26.68	33.35
Capacity, amp-hr.............	100	150	300	300	600
Internal resistance, ohm........	0.089	0.070	0.043	0.025	0.020

253. **The Leclanché cell** is adapted only to intermittent work such as bells, telephones, etc. It is cheap and easy to maintain.

254. **The Leclanché cell is set up** as follows: Put 3 or 4 oz. of salammoniac in the jar; pour about one-third full of water and stir until the salammoniac is all dissolved; place the carbon electrode in the porous cup and pack it around with manganese dioxide and crumbled carbon; then, inserting the porous cup and the zinc electrode into the jar, the cell is ready for use.

Practically the only attendance consists in renewing the evaporated water. The zinc is replaced when worn out. When it becomes necessary to add salammoniac the solution should be thrown out and a new one made. If the porous cell becomes clogged, soaking in warm water will improve it.

The resistance depends upon the dimensions of the electrodes, the state of the porous cup and the condition of the cell. Under proper working conditions and with a carbon-electrode having about 8 sq. in. surface, the resistance will be about 1.5 ohm.

255. **The dry cell** is a very popular form, and does not require any attendance. It is simply thrown away when exhausted. The jar, generally of zinc, forms one electrode. The carbon electrode is suspended in the center of the zinc vessel, care being taken not to allow it to touch the zinc. The zinc is protected by several thicknesses of blotting paper and the chamber filled with a mixture of carbon, manganese dioxide and sawdust (or some absorbent substance), the mixture being saturated with a solution of salammoniac. The top is sealed with wax and the whole cell slipped into a pasteboard box.

Oftentimes the life can be extended slightly by punching a hole in the top and pouring in water.

256. **A storage battery, secondary battery, or accumulator** (*Standard Handbook*) is an electrical device in which chemical action is first caused by the passage of electric current, after which the device is capable of giving off electric current by means of secondary reversed chemical action. Any voltaic couple that is reversible in its action is a storage battery. The process of storing electric energy by the passage of current from an external source, is called *charging* the battery; when the battery is giving off current, it is said to be *discharging*. A storage-battery cell has two elements, or plates, and an electrolyte. The two plates are usually made of the same material, though they may be of two different materials.

257. **The unit of capacity of any storage cell is the ampere-hour** and is generally based on the 8-hr. rate of discharge. Thus a 100 amp-hr. battery will give a continuous discharge of $12\frac{1}{2}$ amp. for 8 hr. Theoretically it should give a discharge of 25 amp. continuously for 4 hr. or 50 amp. for 2 hr. As a matter of fact, however, the ampere-hour capacity decreases with an increase of discharge rate.

258. **The capacity of a cell** is proportional to the exposed area of the plates to which the electrolyte has access, and depends on the quantity of the active material on these plates.

259. **The capacity of batteries** depends, therefore, on the size and number of plates in parallel, their character, the rate of discharge and also on the temperature. Taking the 8-hr. rate of discharge and temperature of 60 deg. fahr. as standard, the capacities which obtain in American practice are from 40 to 60 amp-hr. per

square foot of *positive* plate surface (= no. of positive plates in parallel × length × breadth × 2).

260. **The voltage of any storage cell** depends only on the character of the electrodes, the electrolyte density and the condition of the cell, and is independent of the size of the cell.

261. **The voltage of the lead sulphuric-acid cell,** when being charged is from 2 to 2.5 volts, while on discharge it varies from 2.0 down to 1.7 volts. (See Fig. 133.)

262. **High battery voltages are obtained** by joining the required number of cells in series. Thus for 100-volt circuits, approximately 50 cells in series are required.

263. **The lead storage battery of commerce** is made up with electrodes having their active materials of lead peroxide and sponge lead as the positive and negative electrodes respectively, immersed in a dilute solution of sulphuric acid.

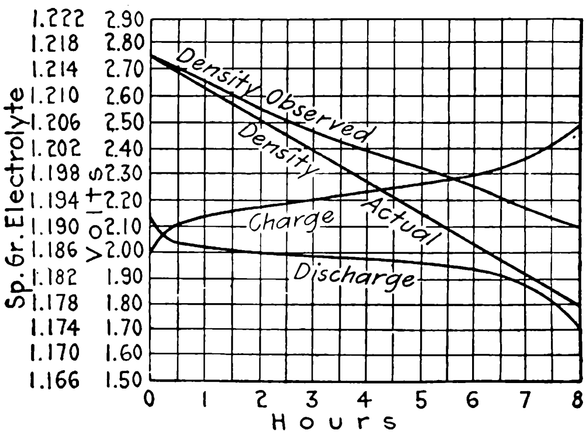


FIG. 133.—Characteristic curves of the lead storage battery.

264. **There are two general types of plates, for lead storage batteries,** namely, the Planté and the pasted, and numerous variations of each of these types. In the Planté type of plate the active materials are formed out of and on the lead surface of the plate itself. Pasted plates are made up by applying the active material by some mechanical process, such as mixing in a paste and spreading on the surface of a grid or plate. The pasted active material has some substance added to it to cause it to set or harden.

265. **The essential differences between the Planté and the pasted plates are**: For a given output Planté plates are more costly, more bulky and heavier than the equivalent pasted plates. They also are more easily injured by impurities in the electrolyte. They are, however, capable of standing more rapid charging and discharging rates without injury. They are less liable to lose their active material and be injured by the accumulation of sediment in the bottom of the cells. They are more durable, and have longer life, and in general they are a more dependable type of plate than the pasted. The pasted, however, for a given output,

are cheap, light and occupy a smaller space. They also are not so badly damaged by impurities in the electrolyte. The efficiency of pasted batteries is lower at high current rates than the Planté type.

Each of these types has its particular place in the art. For work such as motor-car propulsion the pasted battery is better adapted than the Planté, owing to its lightness and low cost. For power-station work the Planté battery is more suitable. There are certain classes of work for which each type is fairly well suited, such as train-lighting, railway-signal and telephone work. In every case all the conditions, commercial as well as technical, must be considered before definitely fixing on the type which is most suitable to meet the requirements.

266. **The electrolyte for lead storage batteries** must be of dilute sulphuric acid made of sulphur and not from pyrites. Pyrite contains iron, and acid made from it must necessarily contain some iron. The presence of this metal in the electrolyte is injurious to the battery plates. An electrolyte need not necessarily be chemically pure, but it must be free from chlorine, nitrates, copper, mercury, arsenic, acetic acid, iron and platinum. It should be tested by a competent chemist or supplied by some reliable company guaranteeing its character and freedom from injurious impurities. It is usually purchased of the desired specific gravity, ready for use, but in cases where it is desirable to save freight, or for other reasons, to make the electrolyte at the point of installation, either distilled water (usually purchasable from a local ice factory) or rain water must be used to dilute the acid. *The acid should be poured into the water—never pour water into acid.* A chemical combination between the water and acid takes place, generating heat, and the solution, which becomes hot, must be allowed to cool before using and before attempting to determine its specific gravity, as the specific gravity changes markedly with the temperature of the liquid. The specific gravity required depends on the character of the cell, its rate of discharge, and its ampere hour capacity. The density is usually specified by the makers of the battery. Experience shows that density should be as low as possible for satisfactory operation, but should not be less than 1.100.

267. **Rules for operation of lead storage batteries** (*Standard Handbook*).

1. Be sure the ELECTROLYTE is free from injurious IMPURITIES.
2. Keep ELECTROLYTE well above tops of PLATES.
3. Maintain the SPECIFIC GRAVITY of the electrolyte at the density specified by the manufacturers of the battery.
4. Do not let the DENSITY of the electrolyte in any cell differ from the standard density more than 0.005. Thus a cell having normal density of 1.200 should register above 1.205 and below 1.195 when fully charged. Test each cell with hydrometer once a week at least.
5. Keep CELLS CLEANED out and remove sediment when it has deposited metal near the lower edges of the plates.
6. Be sure SEPARATORS are all in place and in good order.
7. Note any evidences of TANK LEAKAGE and correct at once.
8. Maintain INSULATION of cells from ground and from each other.
9. Begin CHARGE IMMEDIATELY after the end of discharge or as soon thereafter as practicable.

10. Do NOT CONTINUE CHARGE AFTER the negative plates begin to give off gas, except the occasional "boiling" to be mentioned later.

11. NEVER LET CHARGING CURRENT FALL BELOW the 8-hr. rate except toward the end of charge, and

12. STOP DISCHARGE WHEN the battery potential falls to 1.75 volts per cell with the normal current; 1.70 volts per cell discharging at the 4-hr. or 1.60 volts per cell discharging at the 1-hr. rate.

13. Watch the COLORS OF THE PLATES AND IF they begin to grow lighter treat at once for removal of sulphate.

14. Give the battery a PROLONGED OVER-CHARGE ABOUT ONCE A MONTH. This over-charge should continue at about 60 per cent. of the 8-hr. rate until free gassing of the negative plates has continued for 1 hr.

15. Never let the BATTERY TEMPERATURE rise above 110 deg. fahr. and, if possible, keep below 100 deg. fahr.

16. TEST EACH CELL ONCE A WEEK WITH A CADMIUM ELECTRODE and a low-reading voltmeter to determine the condition of the negative plates.

17. TEST the cells OCCASIONALLY FOR DROP ON DISCHARGE; excessive drop indicates the presence of sulphate, and if the drop increases the amount of sulphation is also increasing.

18. WHEN ONE OF A SERIES OF CELLS IS SULPHATED, charge it as usual in series with the others; on discharge cut the cell out, connecting the opened circuit by a heavy wire joining the two cells adjacent to the sulphated one. Be careful not to short-circuit the latter cell. When discharge is ended, remove connector and switch in the sulphated cell so that it again receives charge. Repeat this process until the cell has had its sulphate fully reduced. A double-pole, double-throw switch is conveniently used to switch the cell and the connector alternately into and out of the circuit. With it the cell may be allowed to discharge a short time before cutting out, which improves the treatment.

19. CELLS WHICH STAND A CONSIDERABLE TIME UNUSED—say as long as 45 days—should work in low density electrolyte not exceeding 1.210 specific gravity and be over-charged as directed in 18. It is better to give them a slight discharge and charge about once a week if practicable.

20. CELLS WHICH ARE TO BE IDLE TWO MONTHS OR MORE should be taken out of commission by first fully charging and then discharging for two hours at the normal rate. Then draw off the electrolyte and fill the cells with pure water, preferably distilled. Begin discharge again at the normal rate. The cells will have to be practically short-circuited to produce this discharge in the water. When the discharge has been carried to a point at which the voltage is about 0.5 volt per cell, the water is poured out of the jars and the plates washed thoroughly by putting a hose in the jar and flowing the water over the plates. Allow the water which fills the jars at the end of the washing to remain 24 hr.; then pour out and allow the electrodes to dry. When the battery is to be used again pour in electrolyte and give a prolonged over-charge.

268. Installation of Lead Storage Batteries.—It is necessary that these cells be insulated from each other. For small glass cells make a shallow wooden box, an inch deep, having a length and breadth greater than the corresponding cell dimensions. Set this box on four glass insulators and fill it with clean sand. On this sand the cell is set. The sand affords a uniform bedding and support for the glass cell and catches and absorbs moisture which may drip down from the sides of the cell.

With lead-lined, wooden tanks, the cells themselves are set directly on glass insulators, there being four insulators under ordinary size cells and six where cells are so long as to require middle supports. It is customary now to set large cells with double insulation, that is, the cells are set on insulators, these insulators rest on a wooden framework, and the wooden framework rests in turn on a set of insulators.

The insulators used are generally of a special form, and are made of both glass and porcelain. Many years of experience have indicated that porcelain is not a proper material, as it is liable to

crack and expose its porous mass so that any electrolyte spray is absorbed into it when it ceases to be an insulator and becomes a fairly good conductor.

269. The Edison Storage Battery (*data furnished by the Edison Storage Battery Co.*) is the result of an effort to avoid many of the disadvantages of the lead sulphuric-acid combination and is a radical departure therefrom in every detail of construction. The positive plate consists of hollow, perforated, sheet-steel tubes filled with alternate layers of nickel hydrate and metallic nickel. The hydrate is the active material; and the metal, which is made in the form of microscopically thin flakes, is added to provide good conductivity between the walls of the tube and the remotest active material. The negative plate is made up of perforated, flat, sheet steel boxes or pockets loaded with iron oxide and a small amount of mercury oxide, the latter also for the sake of conductivity. The grids which support these tubes and pockets are punchings of sheet steel. The cell terminals and container are likewise of steel and all metallic parts are heavily nickel plated. The electrolyte is a 21 per cent. solution of caustic potash containing also a small amount of lithium hydrate. All separators and insulating parts are made of rubber.

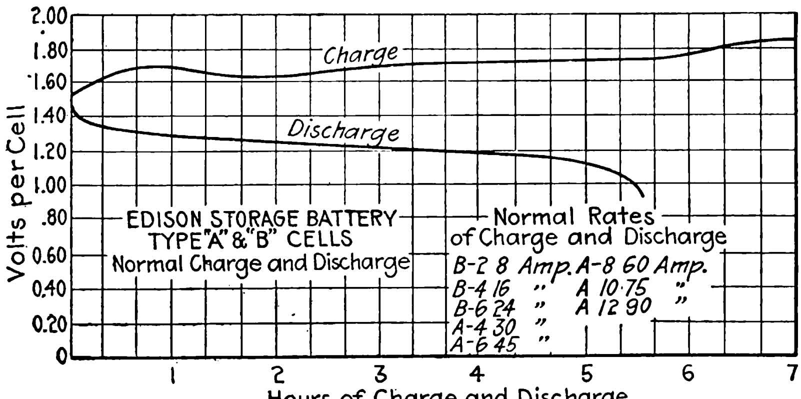


FIG. 134.—Charge and discharge curves of the Edison battery.

The current used in charging causes an oxidation of the positive plate and a reduction of the negative, and these operations on discharge are reversed. The electrolyte acts merely as a medium and does not enter into combination with any of the active material as it does in the acid battery. Its specific gravity remains practically constant throughout the complete cycle of charge and discharge. The charge and discharge curves are shown in Fig. 134.

The chief characteristics of the battery are ruggedness, due to its solid, steel construction; low weight, because of its stronger and lighter supporting metal; long life, because of the complete reversibility of the chemical reactions and the absence of shedding active

material; and low cost of maintenance, due to its freedom from the diseases, such as sulphation, so commonly met with in storage battery practice, and from the necessity of internal cleaning and plate renewals. The arguments against it are high first cost and high internal resistance. The importance of these must, of course, be weighed with the advantages and the resultant considered in each proposed installation. The battery has attained its chief prominence in vehicle propulsion, but its characteristics also recommend it for many other purposes.

The attention required by this battery is of the simplest character. It is chiefly important that the electrolyte be replenished from time to time with distilled water so that the plates will be entirely immersed, and that the outside of the cells be kept clean and dry, for if this is not done leakage of current will occur with consequent corrosion of containers by electrolysis.

270. Efficiency of the Edison Storage Battery (*Standard Handbook*).—The Edison battery is not as efficient from the energy standpoint as are some of the other types, 60 per cent. being the efficiency usually attained in practice. The advantages of the cell lie largely in its mechanical construction and its freedom from deterioration due to rough usage. It is compact and extremely light and strong.

271. Directions for Charging Small Storage Batteries.—Alternating current cannot be used directly. When this only is

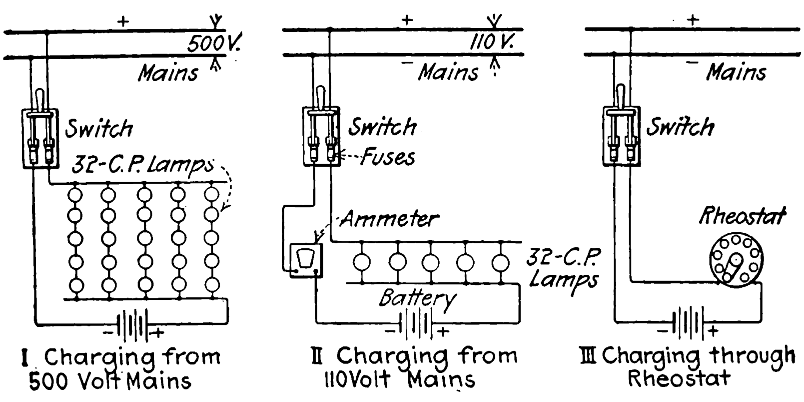


FIG. 135.—Connections for charging storage batteries.

available it must be converted to direct current by means of motor-generators, rotary converters, or mercury-vapor converters. Connections are shown in Fig. 135 for charging small storage batteries from direct-current mains. An ammeter in the circuit is convenient but not absolutely necessary and lamps or a rheostat (Fig. 135, *III*) are used to vary the current. A 16 c-p., 110-volt, carbon-filament lamp has about 220 ohms resistance and will carry 0.5 ampere; a similar lamp of 32 c-p. rating has about 110 ohms resistance and will carry 1 amp. Therefore, the charging current from 110-volt mains (Fig. 135, *II*) can be limited to, say, 5 amp. by connecting five 32 c-p. lamps in parallel, or from 500-

volt mains (Fig. 135, *I*) by connecting in parallel five series of lamps, each series containing five 32 c-p. lamps. In both cases, two 16 c-p. lamps in parallel can be used in place of each 32 c-p. lamp. Charging current must always flow through the battery from the positive pole to the negative pole. See directions elsewhere in this section for determining polarity.

CIRCUIT CALCULATIONS

(The material on Circuit Calculation Considerations that follows was prepared by the compiler of this book and was first printed in *Electrical Review*, March 8, 1913, under the pen name of Anthony Gorman.)

272. **There are three factors that should be considered** when determining the sizes of wires for the distribution of electricity. A wire should be of such size that: (1) It will carry the electricity to the point where it will be used without an excessive drop or loss of voltage; (2) the current will not heat it to a temperature that would spoil the insulation or cause a fire (see Table 170 of *safe carrying capacities*); and (3) the cost of energy lost—the I^2R loss—due to the current overcoming the resistance will not be excessive. A conductor may satisfy one of the three conditions and may not satisfy the other two.

273. **The Voltage Drop Allowable in Lamp Circuits.**—For a 110-volt incandescent lamp load the conductors should be of such size that the pressure at the lamps can never vary more than 3 volts. Sometimes 4 and even 5 volts variation is allowed on 110-volt lamp circuits. This is not good practice. Expressed in percentages, a 1 per cent. to a 3 per cent. drop represents good practice; a 4½ per cent. drop is the upper limit. These are percentages of the receiver or normal lamp voltage. If the values above suggested are exceeded the life of the lamps may be shortened or they may burn dimly when the circuits are loaded.

274. **The Voltage Drop Allowable in Motor Circuits.**—A drop of 5 per cent. is very good practice and a 10 per cent. drop is often permitted. If motors are on the same circuits with lamps a 3 per cent. drop should not be exceeded. The question of voltage drop in conductors is closely associated with that of conductor economy. In important work particularly where the cost of energy is high, the cost of the energy lost in a conductor as well as the volts lost in it should be considered.

275. **Per cent. line drop or voltage loss** may be figured as either a percentage of the voltage required at the receiver or as a percentage of the voltage impressed by the generator or other energy source on the line. For instance, in Fig. 136, the voltage impressed on the receivers—lamps and motor—is 220. The line loss is 11 volts, hence, the pressure impressed on the line $= 220 + 11 = 231$ volts. The voltage loss as a percentage of the voltage at the receiver $= \frac{11}{220} = 0.05 = 5$ per cent. The voltage loss as a percentage of the voltage impressed on the line is $\frac{11}{231} = 0.048 = 4.8$

per cent. In practical work the percentage loss or drop is usually taken as a percentage of the voltage required at the receivers because this is the most convenient and direct method. In this book the term "percentage drop" refers to a percentage of the voltage required at the receivers unless otherwise noted.

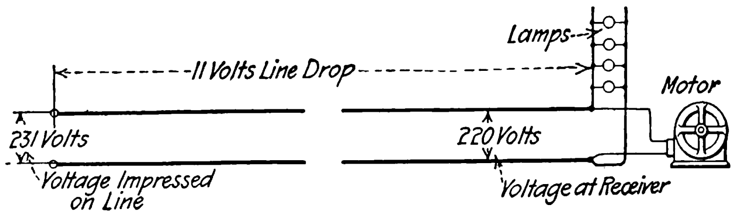


FIG. 136.—Illustrating percentage line drop.

276. To ascertain the volts drop as a percentage of the volts impressed on the line, use the following formula:

$$V = \frac{E \times p}{100 - p} \qquad \text{(volts)}$$

wherein V = volts drop or loss in line, p = percentage drop of the voltage impressed on the line and E = voltage at the receiver.

Example.—What will be the voltage drop in a circuit where 110 volts is to be impressed on the receivers—lamps, motors or other equipment—and the allowable drop is 4 per cent. of the voltage impressed on the circuit.

Solution.—Substitute in the above formula:

$$V = \frac{E \times p}{100 - p} = \frac{110 \times 4}{100 - 4} = \frac{440}{96} = 4.58 \textit{ volts.}$$

Table 277 gives actual line drops for different percentages of voltages impressed on the line.

277. Volts Lost at Different Per cent. (of Voltage Impressed On Circuit) Drop (*Standard Handbook*)

Per cent. drop	Voltage impressed on receivers		Per cent. drop	Voltage impressed on receivers	
	110	220		110	220
0.5	0.552	1.10	8	9.56	19.13
1	1.11	2.22	9	10.87	21.75
1.5	1.67	3.35	10	12.22	24.44
2	2.24	4.48	11	13.59	27.19
2.5	2.82	5.64	12	14.99	29.99
3	3.40	6.80	13	16.43	32.87
4	4.58	9.16	14	17.90	35.81
5	5.78	11.57	15	19.41	38.82
6	7.02	14.04	20	27.50	55.00
7	8.27	16.55	25	36.66	73.33

278. Distribution of Drop in Wiring Systems.—It is necessary in designing circuits to apportion the total allowable drop between the components of a wiring system, the feeders, mains and branches. The Table 279 indicates good practice for lighting circuits at 110 volts.

279. Distribution of Drop in 110-volt Lighting Circuits

Part of circuit	Proportion	4 volts total drop		3 volts total drop	
		Actual drop	Per cent. drop	Actual drop	Per cent. drop
Branches	1 volt	1 volt	0.91	1 volt	0.91
Mains	⅓ remainder	1 volt	0.91	⅔ volt	0.60
Feeders	⅔ remainder	2 volts	1.82	1⅓ volt	1.21
Total		4 volts	3.64	3 volts	2.72

In incandescent lamp electric lighting most of the drop should be confined to the feeders so that all of the lamps on mains and branches served by the same feeder will burn at about the same brilliancy. If most of the drop is in the mains and branches, lamps located close together but served by different mains may burn at decidedly different brilliancies and may attract attention and cause comment. Fig. 137 illustrates drop distribution.

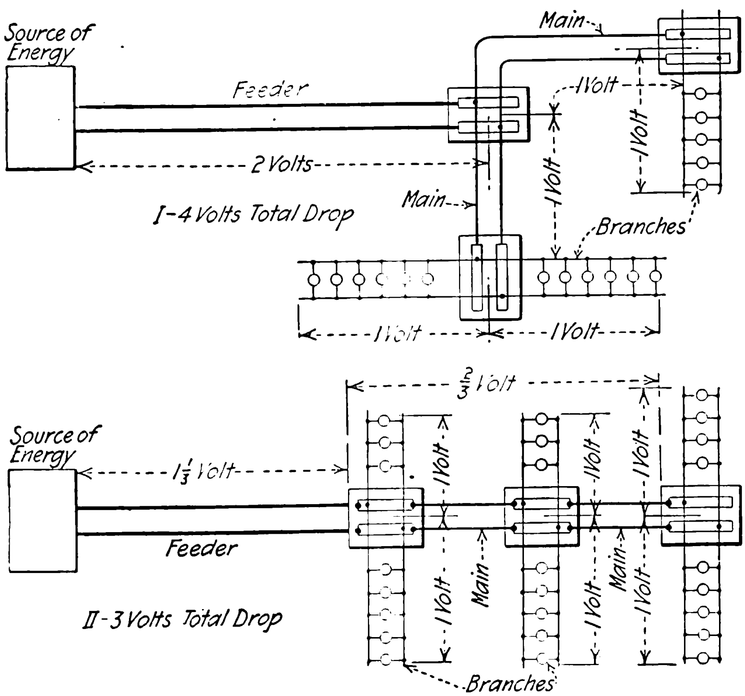


Fig. 137.—Distribution of drop in lighting circuits.

With motor circuits it is desirable to confine most of the drop to the mains so that a variation in the load on one motor or group of motors will affect the speeds of the others as little as possible. If most of the drop is in the feeder, a heavy overload on one motor might cause a very appreciable drop in the feeder and the voltages impressed on all the motors, served by the feeder, would be corre-

spondingly decreased. The speeds of all of the motors served by the feeder would be lowered accordingly. In general, on low-voltage motor circuits, 1 volt drop can be allowed in the branches, two-thirds of the remaining allowance in the mains and one-third of the remaining allowance in the feeder. See Fig. 138 which

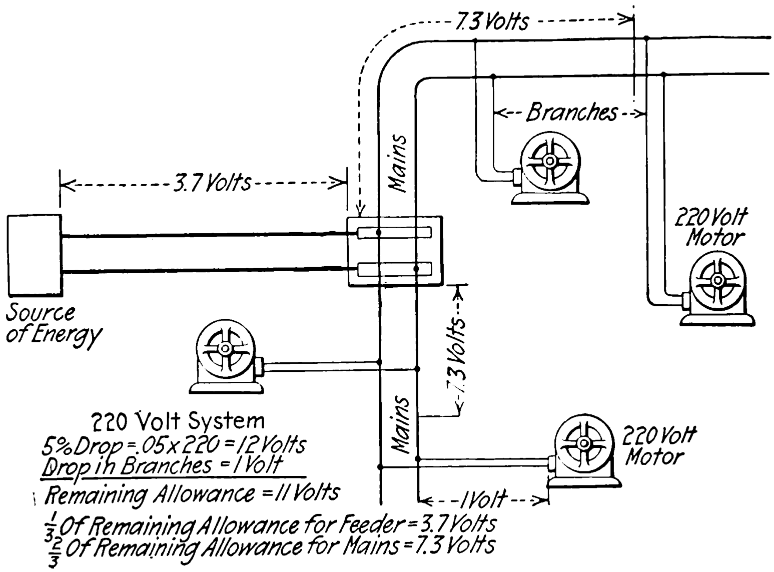


FIG. 138.—Distribution of drop in feeder-and-main 220-volt motor circuit.

shows the drop distribution for a system wherein the total allowable drop is 5 per cent.

Where a wiring system is not laid out in accordance with a feeder and main system, the drop must be apportioned among the conductors in accordance with the judgment of the designer, but

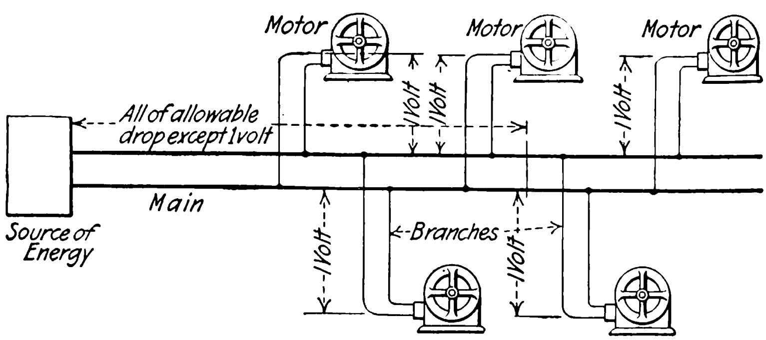


FIG. 139.—Distribution of drop in main-and-branch motor circuit.

the principles outlined above should be considered. Where a motor circuit consists only of a main and branches (Fig. 139) one method is to allot 1 volt drop to the branches and the balance of the permissible drop to the main. Where motor branches are not

very long the drop in them (because they must be large enough to carry full-load current without overheating) is frequently not far from 1 volt with full-load current. It may, in practice, be often assumed that it is 1 volt. Motor branches must be large enough to safely carry a current 25 per cent. greater than the full-load current because of *N.E.C.* regulations.

280. **Safe current carrying capacity** should always be considered when designing circuits. A wire may be large enough to carry a given current a given distance without undue drop, but yet so small that the current will overheat it. After a conductor size has been selected with reference to drop, Table **170** of safe current-carrying capacities should be consulted. If the wire first selected is not large enough to safely carry the current one that is large enough should be used. The matter of safe current-carrying capacity must be watched very closely in circuits that are short.

281. **The resistance of a circular mill-foot of commercial copper,** that is, a wire 1 ft. long and having an area of one cir. mil, at a temperature of 75 deg. fahr., is usually given as from 10.6 to 10.8 ohms. For wiring calculations 11 ohms is sufficiently accurate. (*Standard Handbook.*) In wiring calculations it is useless to exercise refinement, especially as the purity of the copper is unknown, the circuit lengths are often not measurable to within many per cent. of accuracy, and the difference between the successive sizes of wire available on the market, that is, the even numbered sizes, is about 60 per cent. There are other undeterminate factors.

282. **How to Proceed in Determining Wire Sizes for Circuits.**—Nearly every wiring problem involves the finding of the size wire that will carry a given current a given distance with a given drop in volts. The steps to be taken in finding the wire size in any such problem are as follows.

A. Determine the load in amperes that will come on the circuit. This ampere load value will be used in taking the wire size from a table or will be substituted for the letter I in a formula. See **284.**

B. Find the distance to the load center of the circuit. See **285.** This distance will be the actual length if the load is concentrated at the end or it will be the distance to the load center if the load is distributed. When found, this distance is used as the length of the circuit and is substituted for the letter L in a formula.

C. Decide what voltage drop or volts drop is allowable. See **273** and **274.**

D. Determine the wire size that will give the voltage drop decided on in C by using one of the formulas that follow, using the values for distance and volts drop of B and C.

E. Check the wire size determined in D to see that it is large enough to safely carry the current by Table **170.** See **280.** If the size first selected is not large enough, one that is big enough to safely carry the current must be used.

F. Where economy of operation is a factor, check the size conductor as determined by D and E to be sure that the cost of the energy wasted in it in overcoming its resistance will not be excessive. See **286** and **287.**

283. In determining circuit lengths from drawings or blue prints a long piece of tough paper divided (see Fig. 140) into the same measure as the drawing can be effectively used in scaling distances. Always allow for rises or drops for wall outlets. The

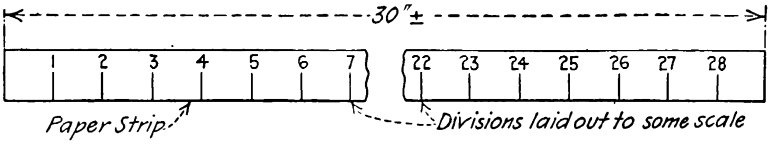


FIG. 140.—Paper scale for measuring circuit lengths.

rotometer (Fig. 141), is a convenient tool for scaling distances. The little wheel is run over the course of the circuit. The pointer indicates feet direct for drawings of certain scales. For other scales the dial reading must be multiplied by a constant to obtain actual lengths. A rotometer costs $2.00 or $3.00.

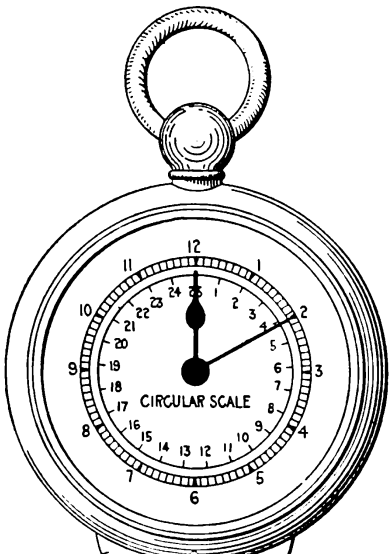


FIG. 141.—A rotometer.

284. Determination of Loads That Will Come on Conductors.—It is necessary to determine the load in amperes that will come on each conductor in a wiring system for figuring the wire sizes and so that one may be sure that the wire will safely carry the current. Where drawings are available note the ampere loads on the sheet in pencil as shown in Fig. 142. The figures opposite the receivers indicate the currents they take. The total load on each branch main and feeder is indicated within a circle. Motor branch circuits must be large enough to safely carry 25 per cent. more

than full-load current. It is convenient to note a current 25 per cent. greater than full-load current in a square near each motor branch, as in Fig. 142, so that the wire for the branch can be checked for carrying capacity. The numbers of amperes required by lamps, motors and other devices are given in tables elsewhere in this book.

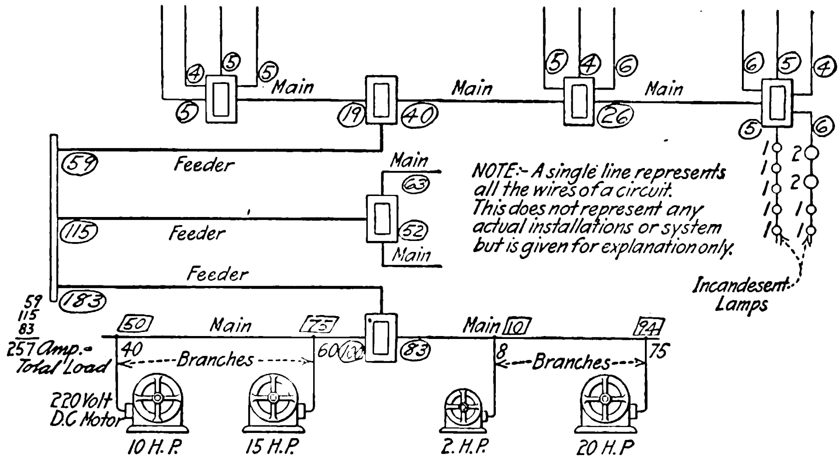


FIG. 142.—Determination of loads on conductors.

285. The location of the load center of a circuit is that point at which the total load can be assumed to be concentrated when making wiring calculations. The letter L in the wiring formulas in this book stands for the distance to the load center. The load center of a group of receivers, symmetrically arranged (Fig. 143)

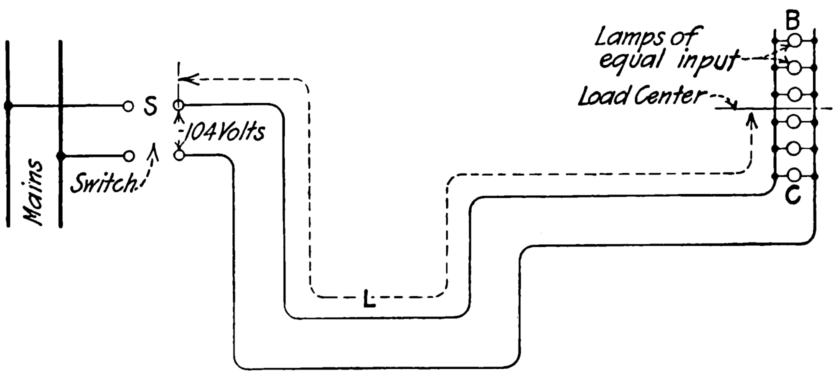


FIG. 143.—Illustrating location of load center.

and all of the same input will be in the middle of the group. Always take the distance along the circuit as L, Fig. 143.

The distance to the load center (Fig. 143) denoted by L would be used for L in the wiring formula cir. mils $= 22IL \div V$. The drop of voltage, V in the formula, would be the drop from the switch S to the last lamp, B. The current, I in the formula,

would be the total current taken by all 6 lamps. If the conductors were calculated for a drop of 5 volts, the drop between S and B would be 5 volts. If 110 volts was impressed at S, the voltage at B would be $110-5=105$ volts. The other 5 lamps in the group

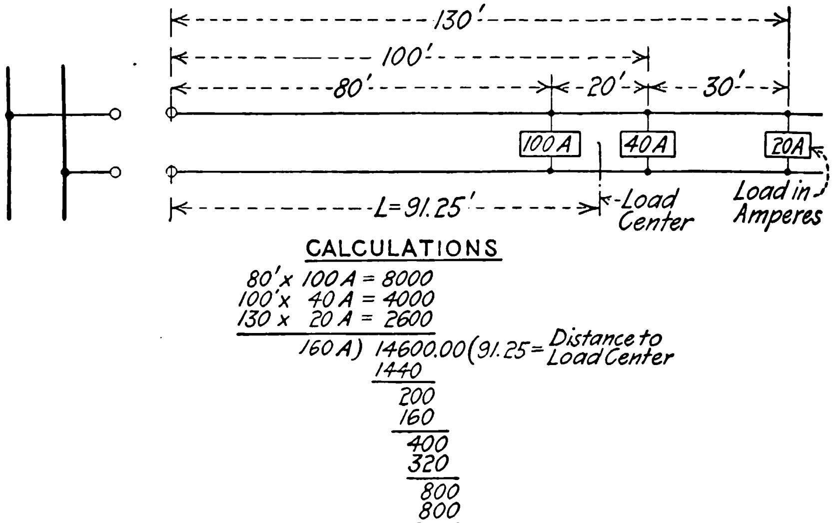


FIG. 144.—Method of computing location of load center.

would receive something greater than 105 volts, the pressure increasing slightly along the circuit toward the switch. The lamp C would receive the highest pressure of all.

The load center of a group of receivers unsymmetrically located or of unequal capacities or of both is found by: (first) multiplying

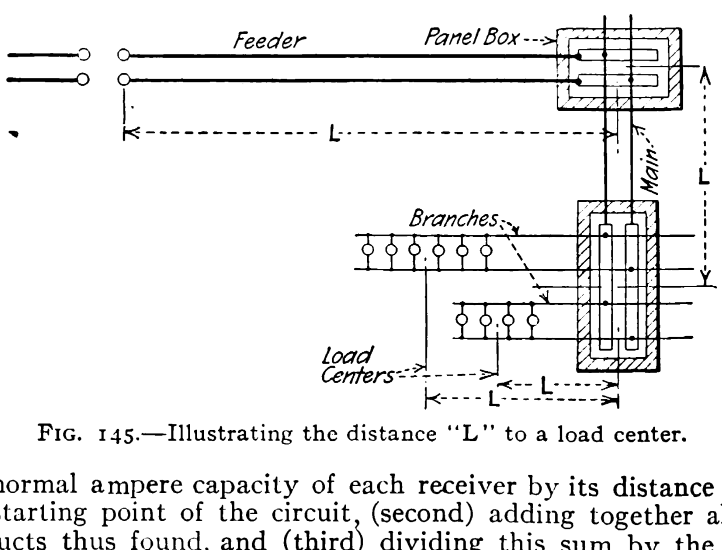


FIG. 145.—Illustrating the distance "L" to a load center.

the normal ampere capacity of each receiver by its distance from the starting point of the circuit, (second) adding together all the products thus found, and (third) dividing this sum by the total current of the circuit. See solution of example in Fig. 144.

Where no energy is taken from a circuit except at its end, the distance L for the formula is, as shown in Fig. 145, the entire length of the circuit. Always measure L along the circuit. In practice the load center is usually determined by inspection because great accuracy is not essential. A beginner should calculate a few examples until he is familiar with the principles involved.

286. **For calculating direct-current two-wire circuits** the following formula is used: (The material on Wiring Calculations that follows was prepared by the compiler of this book and was first printed in *Electrical Review*, June 14, 1913, under the pen name of N. V. Dunne.)

$$\text{cir. mils} = \frac{22 \times I \times L}{V}$$

Wherein V = drop in volts in the circuit, I = the current in amperes in the circuit, L = the length one way or single distance of the circuit in feet and *cir. mils* is the area of the conductor in circular mils. Other forms of the formula are:

$$V = \frac{22 \times I \times L}{\text{cir. mils}} \qquad I = \frac{\text{cir. mils} \times V}{22 \times L} \qquad L = \frac{\text{cir. mils} \times V}{22 \times I}$$

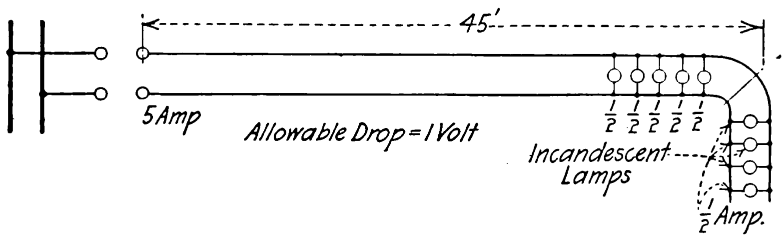


FIG. 146.—An example in wire size determination.

Example.—What size wire should be used for the branch circuit of Fig. 146? Allowable drop to the furthest lamp is 1 volt. Load consists of 10 incandescent lamps each taking ½ amp. Distance from starting point of circuit to load center is 45 ft.

Solution.—Substitute in the formula:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 5 \times 45}{1} = 4{,}950 \text{ cir. mils.}$$

Referring to Table 170, the standard size wire next larger than 4,950 cir. mils is No. 12 which has an area of 6,530 cir. mils. No. 12 wire, rubber insulated (for concealed work), safely carries, as given in the National Code column of the table, **20** amp., hence it will readily carry the 5 amp. of the circuit in question.

Example.—What size wire should be used for the 220-volt motor main of Fig. 147? The motors, so the table of motor currents (see index) shows, take approximately the currents indicated. The total load is (114 amp. + 40 amp.) 154 amp. Allowable drop is 5 per cent. or 11 volts to the furthest motor. Distance to load center is 120 ft.

Solution.—Substitute in the formula thus:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 154 \times 120}{11} = \frac{406{,}560}{11} = 36{,}960 \text{ cir. mils.}$$

Referring to Table 170, No. 4 wire, which has an area of 41,740 cir. mils, is the next largest standard size wire and would keep the drop within the 11 volts allowed. But a No. 4 rubber insulated wire has a safe carrying capacity of but **70** amp. The circuit under consideration carries 154

amp; hence the smallest rubber insulated wire (Code rules) that can be safely used is a No. 000 which has a safe capacity of 175 amp. No. 00, which safely carries 150 amp., could be probably safely used if the wiring inspector would pass it.

Branch leads to motors must (National Electrical Code) have a carrying capacity of 25 per cent. in excess of the full-load current ratings of the motors they serve. With a main serving several motors, the 25 per cent. excess capacity is not required.

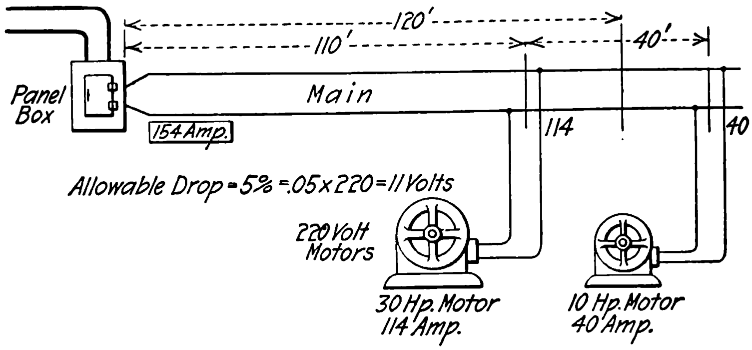


FIG. 147.—Determining wire size for main.

287. Calculations of three-wire, direct-current circuits are made in essentially the same manner as those for direct-current, two-wire circuits. With a balanced three-wire circuit, no current flows in the neutral wire. In practice the circuits should be very nearly balanced and in making wiring calculations it is usually assumed that they are balanced unless there is obviously great unbalance. The first step is to ascertain the current that will flow in the outside wires. This is obtained in practice by adding together the currents taken by all of the receivers connected between the neutral and the outside wires and dividing the sum by 2. (See Fig. 148.) Then to this value are added the currents taken by receivers, if there are any, that are connected across the outside wires. The sum is taken as the total current. The calculation is then made in the same way as for any two-wire circuit. The neutral wire is disregarded in the calculation as it is assumed that it carries no current. The neutral is frequently made smaller than the outside wires. (See Par. 237, Sect. I.)

The drop in voltage, V in the formulas, is the drop in the outside wires and is two times the drop to each receiver between neutral and outside wires. Two-wire branch circuits feeding from three-wire mains or feeders are computed in the same manner as for any two-wire circuit.

Example.—What size wire should be used for the three-wire main of Fig. 148? Allowable drop is 3 volts and the distance to the load center is 40 ft. The circuit is loaded with two groups of receivers each taking 60 amp., connected between the neutral and the outside wires, and one group of receivers taking 20 amp. connected across the outside wires.

Solution.—Load $= \frac{60+60}{2} + 20 = 80$ amp. Substitute in the formula:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 80 \times 40}{3} = \frac{70{,}400}{3} = 23{,}470 \text{ cir. mils.}$$

Referring to Table 170, 23,470 cir. mils correspond most nearly to No. 6 wire which has an area of 26,250 cir. mils. This size wire would satisfy the voltage drop requirements but, for concealed wiring, rubber insulated wire must be used and rubber insulated No. 6 (see Table 170) has a safe carrying capacity of but 50 amp. The current in the circuit is 80 amp. Therefore, with rubber insulated wire No. 3 should be used which will safely carry 80 amp. The neutral wire may be made the same size as the outside wires or it may be smaller (see Par. 237, Sect. I). For exposed wiring with slow-burning or weather-proof insulation, three No. 5 wires each of which safely carries 80 amp. could be used.

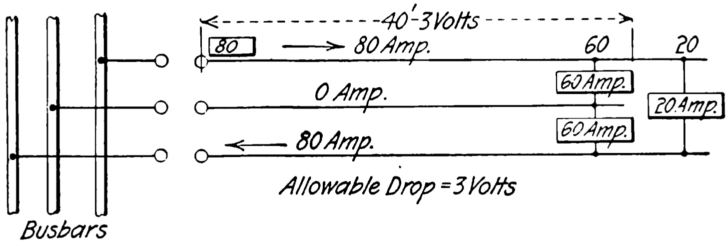


FIG. 148.—A three-wire circuit problem.

288. In calculating alternating-current circuits there are certain phenomena that must be considered that do not exist with direct-current circuits. Among these are the effects of power factor and of induction which creates reactance. Where circuits are short these effects need not always be considered, but where circuits are long they may be of considerable consequence. Capacity seldom need be considered with circuits operating at the voltages discussed in this book, namely, those of pressures below 2,200 volts. Skin effect is usually of so little consequence that it can be neglected.

There is no simple method of calculating alternating-current circuits, that takes into account the effects of power factor and reactance, that is reasonably accurate under all conditions. The methods described in following paragraphs, in which the effect of line reactance is not considered, give approximate results, but experience has shown them to be quite accurate enough for many wiring calculations. The results from these approximate formulas are usually subject to less error than other factors entering into ordinary wiring calculations. The results from the Mershon diagram method are quite accurate.

289. Large Conductors Should not be Used for Alternating-current Circuits.—If conductors are too large, the skin effect becomes so great that but a small proportion of the total area of the conductor is effective. Some engineers will use no conductor larger than 300,000 cir. mils for interior wiring, but 700,000 cir. mil conductors can be used economically for interior work if they are made upon a fiber core as described in 182. As a general proposition, conductors larger than 700,000 cir. mils are very difficult to install. If, for instance, a carrying capacity equivalent to 800,000 cir. mils is required, use two 400,000 cir. mil conductors in parallel or a similar equivalent arrangement.

290. Power factors of the load apparatus or equipment must often be known before alternating-current wiring calculations can

be made. If the exact power factor of the load is not known or cannot be readily obtained the approximate values of Par. 57 can be used. Or for ordinary wiring calculations, it can be assumed that power factors of loads will be as follows: Incandescent lighting load, from 100 per cent. to 95 per cent.; incandescent lighting and motors, 85 per cent.; motors only 80 per cent. The power factor of the load, if it be other than 100 per cent., may affect the volts loss in the line considerably. See examples in the following paragraphs.

291. **Effect of Line Reactance.**—Practically all alternating-current circuits have some line reactance. The effect of reactance is to cause a drop in voltage somewhat similar to that caused by resistance. Where all of the wires of a circuit, two wires for a single-phase, four wires for a two-phase and three wires for a three-phase circuit, are carried in the same conduit or where the wires are separated less than an inch between centers, the effect of line (inductive) reactance may ordinarily be neglected. Where circuit conductors are large and widely separated from one another and the circuits are long, the effect of inductive reactance may increase the volts line loss considerably over that due to resistance alone. Every such case should be investigated with the Mershon diagram (Fig. 158). With aerial circuits on pole lines, where the wires are widely separated, the effect of inductive reactance is apt to be large. Line reactance increases somewhat as the size of wire decreases, and decreases as the distance between wires decreases. (See Table 306.)

292. **Line or circuit reactance with a conductor of given area can be reduced in two ways.** One of these is to diminish the distance between wires. The extent to which this can be carried is limited, in the case of a pole line, to the least distance at which the wires are safe from swinging together in the middle of a span. In inside wiring, knob or cleat work, it is limited by the separation distances required by the underwriters. In conduit work the conductors lie so close together that there is very little effect from inductive reactance under ordinary conditions. The other way of reducing reactance is to divide the copper into a greater number of circuits. Voltage drop in lines due to inductive reactance is best diminished (Mershon) by subdividing the copper or by bringing the conductors closer together. It is little affected by changing the size of conductor. See 301 for a problem illustrating this and its solution.

293. **Calculation of alternating-current incandescent lighting installations.** The following method, though not strictly accurate, can be used for ordinary house and building single-phase wiring where the power factor of the load is nearly 100 per cent., as with incandescent lamps: *Treat the circuits as if they were direct-current circuits using the formula of* 286. *See the example following that paragraph.* If the circuits are very long and the wires widely separated use the method of 299.

294. **Three-wire, single-phase, alternating-current circuits can be calculated,** provided they are of moderate length, with the three-wire direct-current formula of 287. If the circuit is quite

long and the wires widely separated use the method of **300.** Treat the circuit as a single-phase circuit of the voltage between the two outside wires of the three-wire system, disregarding the neutral wire. Then make the neutral wire the same size as is found for the two outside wires.

295. Calculation of Single-phase Alternating-current Circuits where Line Reactance Can be Neglected.—This method, although not strictly accurate, can be safely used for computing short branch circuits and also feeders and mains where the circuits are carried in conduit or are not very long. Where circuits are of considerable length, the method of **300** should be used. If the current is not known it must be found, using this formula:

$$I = \frac{kw. \times 1000}{E \times p.f.}$$

Wherein, I = current in amperes, $kw.$ = kilowatts input of load, E = voltage of circuit and $p.f.$ = power factor of load. The current being known, use this formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V}$$

Wherein, cir. mils = area of conductor, I = current in amperes, L = single distance or length one way of the circuit, in feet, and V = volts drop allowable.

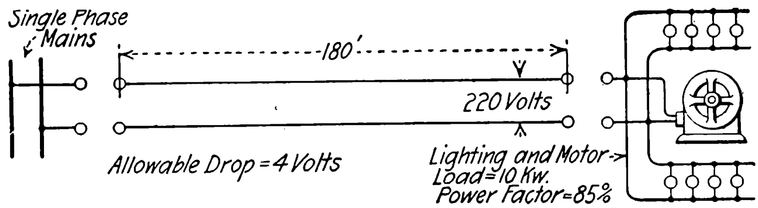


FIG. 149.—Single-phase circuit problem.

Example.—See Fig. 149. Load = 10 kw., voltage of circuit = 220, power factor = 0.85, distance is 180 ft., allowable drop = 4 volts. What size wire should be used?

Solution.—Substitute in the formula:

$$I = \frac{kw. \times 1000}{E \times pf.} = \frac{10 \times 1000}{220 \times 0.85} = \frac{10{,}000}{187} = 53.5 \text{ amp.}$$

Then to find the size conductor:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 53.5 \times 180}{4} = \frac{211{,}860}{4} = 52{,}965 \text{ cir. mils.}$$

Referring to Table **170**: The next larger standard size wire is No. 2 (66,370 cir. mils). It safely carries 90 amp. so is ample for the 53.5 amp. of this problem.

296. Calculation of Two-phase, Four-wire, Alternating-current Circuits where Line Reactance can be Neglected.—The following method, although not strictly accurate, can be safely used for computing short branch circuits and also feeders and mains where the circuits are carried in conduit or are not very long. Where circuits are of considerable length, the method of **301** should be used. If the current is not known, it must be found using this formula:

$$I = \frac{kw. \times 1000}{E \times p.f. \times 2} = \frac{kw. \times 500}{E \times p.f.}$$

Wherein, I is the current in amperes in each of the four wires, $kw.$ = kilowatts input to load, E is the voltage across each of the two phases and $p.f.$ = the power factor of the load. The current being known:

$$\text{cir. mils} = \frac{22 \times I \times L}{V}$$

Wherein, cir. mils = area of required conductor, I = current in amperes in each of the four wires, L = the length or single distance of the circuit in feet, and V = volts drop to be allowed in the circuit.

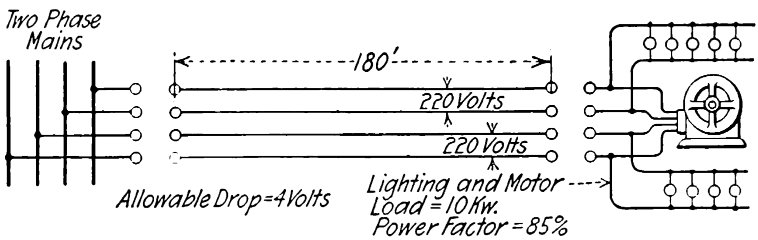


FIG. 150.—Two-phase circuit problem.

Example.—See Fig. 150. Load = 10 kw., voltage of circuit = 220, power factor = 0.85, distance is 180 ft., allowable drop is 4 volts. What size wire should be used?

Solution.—Substitute in the formula:

$$I = \frac{kw. \times 500}{E \times p.f.} = \frac{10 \times 500}{220 \times 0.85} = \frac{5{,}000}{187} = 26.8 \text{ amp.}$$

Then to find the size conductor:

$$\text{Cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 26.8 \times 180}{4} = \frac{106{,}128}{4} = 26{,}532 \text{ cir. mils.}$$

Referring to Table 170: The next larger standard size wire is No. 5 which has an area of 33,100 cir. mils and which will safely carry, with rubber insulation, 55 amp. and with other insulations, 80 amp. It will, therefore, with either insulation, readily carry the 26.8 amp. in this circuit. Four No. 5 conductors would be used.

297. Calculation of Three-phase, Three-wire, Alternating-current Circuits where Line Reactance can be Neglected.—This method, although not strictly accurate, can be safely used for computing ordinary branch circuits and also for computing feeders and mains where the circuits are carried in conduit or are not very long. Where circuits are of considerable length, the method of 302 should be used. If the current is not known, it must be found, using this formula:

$$I = \frac{kw. \times 1{,}000}{E \times p.f. \times 1.73} = \frac{kw. \times 580}{E \times p.f.}$$

Wherein, I = current in amperes in each of the three wires, E = voltage between wires, $kw.$ = kilowatts input to load, and $p.f.$ = power factor of load. The current being known, the wire size can be calculated thus:

$$\text{cir. mils} = \frac{11 \times I \times L \times 1.73}{V} = \frac{19 \times I \times L}{V}$$

Wherein, cir. mils = area for each of the three wires, I = current in each of the three wires in amperes, L = single distance or length one way of the circuit in feet, and V = allowable volts drop in line.

Example.—See Fig. 151. Load = 10 kw., voltage of circuit = 220, power factor = 0.85, distance is 180 ft., allowable drop = 4 volts. What size wire should be used?

Solution.—Substitute in the formula:

$$I = \frac{kw. \times 580}{E \times p.f.} = \frac{10 \times 580}{220 \times 0.85} = \frac{5,800}{187} = 31 \text{ amp.}$$

Then to find the conduction size:

$$\text{Cir. mils} = \frac{19 \times I \times L}{V} = \frac{19 \times 31 \times 180}{4} = \frac{106,000}{4} = 26,500 \text{ cir. mils.}$$

Referring to Table **170**: The next larger standard size wire is No. 5 which has an area of 33,100 cir. mils. It will safely carry with rubber insulation 55 amp., and with other insulations 80 amp. It is therefore ample in section for the 31 amp. of this problem. Three No. 5 wires would be used for the circuit.

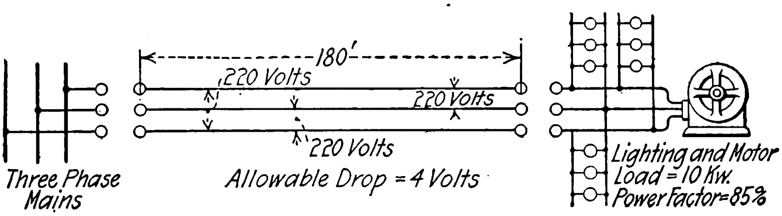


FIG. 151.—Three-phase circuit problem.

298. Single-phase branches from three-phase circuits are calculated the same as any single-phase circuit. If the two-branch conductors are tapped from two of the conductors of a three-wire, three-phase circuit, the voltage across the branch wires will be the same as that across two of the wires of the three-phase circuit. If the branch is connected between one of the three wires and neutral, the voltage across the branch wires will be 0.58 × the three-phase voltage between wires. See paragraphs on the three-phase system under "Alternating Currents."

299. Calculation of Circuits where Line Reactance must be Considered.—The Mershon diagram (Fig. 158) is recommended for making such calculations. Other and apparently simpler methods are available, but all simple methods are inaccurate under certain conditions and are apt to get their user into trouble unless he is quite familiar with the principles of alternating currents. The Mershon diagram does not offer a direct method of ascertaining drop. It is rather a "cut-and-try" method. The distance between wires and the frequency of the circuit being known, a conductor of a size that appears to be about right is selected for trial. With the known current flowing, the volts line loss in this conductor can be determined with the diagram. If the volts line loss with this conductor is found to be excessive a different size conductor is tried. Trials are made until a size conductor is found that will bring the drop within the specified limit. It is seldom that more than two trials are necessary. The method is a little tedious, but not difficult. It is accurate under all ordinary conditions. See the examples that follow.

300. Calculation of Single-phase Alternating-current Circuits where Line Reactance must be Considered.—The use of the **Mershon diagram** in computing such circuits can best be explained by examples.

Example.—What size wire should be used for the branch to the 50-h.p., 60-cycle, 250-volt, single-phase induction motor of Fig. 152? The name-plate current rating of the motor is 195 amp. and its full-load power factor is 85 per cent. The wires are run open and separated 4 in. Length of circuit is 600 ft. The volts line loss must not exceed 7 per cent. or $0.07 \times 250 = 17.5$ volts.

Solution.—To ascertain approximately what size the conductor must be, use the simple single-phase formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 195 \times 600}{17.5} = 147{,}000$$

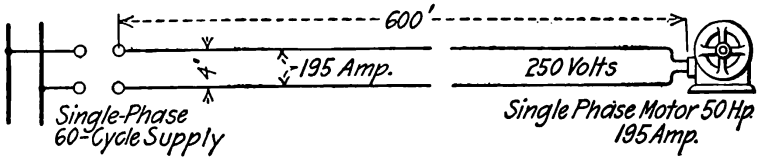


FIG. 152.—Another single-phase circuit problem.

Referring to Table 306: The next larger standard size wire is No. 000 or 167,800 cir. mils. This size would be ample if there were no line reactance, but as it is known that there is line reactance we will select a larger conductor and find what the volts loss with it will be, using the Mershon diagram (Fig. 153). Try a 250,000 cir. mil conductor.

Find the resistance and reactance drops in the line using the values from Table 306 for a 250,000 cir. mil conductor for 60 cycles and a 4 in. separation. From the table *resistance volts* = 0.085 and *reactance volts* = 0.139.

$$\text{Resistance drop} = \frac{\text{current} \times \text{resistance volts} \times \text{distance}}{1{,}000} = \frac{195 \times 0.085 \times 600}{1{,}000} = 9.9 \text{ volts}$$

$$\text{Per cent. of resistance drop} = \frac{\text{resistance drop}}{\text{receiver volts}} = \frac{9.9}{250} = 3.96 \text{ per cent.}$$

$$\text{Reactance drop} = \frac{\text{current} \times \text{reactance volts} \times \text{distance}}{1{,}000} = \frac{195 \times 0.139 \times 600}{1{,}000} = 16.3 \text{ volts.}$$

$$\text{Per cent. of reactance drop} = \frac{\text{reactance drop}}{\text{receiver volts}} = \frac{16.3}{250} = 6.5 \text{ per cent.}$$

Refer to the Mershon diagram (Fig. 158). Follow the vertical line corresponding to the power factor, 0.85, upward until it intersects the smallest circle marked *O* as illustrated in Fig. 153. From this point lay off horizontally the percentage resistance drop, 3.96. From this last point lay off vertically the percentage reactance drop, 6.5. (See Fig. 153.) This last point lies about on the 7 per cent. circle indicating that the volts line loss in this circuit with 195 amp. flowing will be $0.07 \times 250 = 17.5$ volts. The conditions of the example are satisfied by a 250,000 cir. mil conductor. Actually the line loss will be somewhat less than 7 per cent. as the last point does not quite touch the 7 per cent. circle.

Inasmuch as this is a motor branch, the code rules require that its safe carrying capacity be sufficient for a 25 per cent. over-load. Therefore the conductor should be capable of safely carrying $195 \times 1.25 = 244$ amp. Referring to Table 306, a 300,000 cir. mil conductor, rubber insulated cable would be required to safely carry this 244 amp. In a problem in practice one would, therefore, immediately try a 300,000 conductor for volts line loss. The preliminary calculations were given in the above problem to illustrate the method.

301. Calculation of Two-phase, Four-wire, Alternating-current Circuits where Line Reactance must be Considered.—Use the Mershon diagram (Fig. 158). Calculate the single-phase circuit required to transmit one-half the power at the same voltage. The two-phase transmission will require two such circuits.

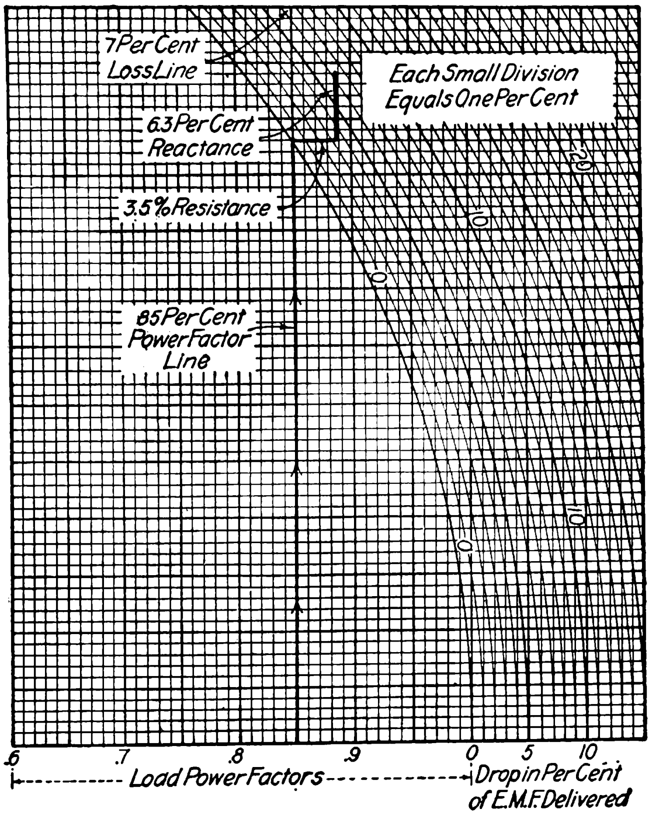


FIG. 153.—Illustrating the application of the Mershon diagram for computing a single-phase circuit.

Example.—What size wire should be used for the two-phase circuit of Fig. 154? Load = 120 kw.; receiver voltage = 220; load power factor = 80 per cent.; frequency = 60 cycles; length of circuit = 400 ft.; distance between wires = 6 in. Allowable loss (voltage drop) is 5 per cent.

Solution.—Find one-half of the total load on the circuit and then proceed with this one-half total load as if it were the entire load on a single-phase circuit.

$$\tfrac{1}{2}\text{ total load} = \frac{120\ kw.}{2} = \frac{120{,}000\text{ watts}}{2} = 60{,}000,\text{ watts}$$

$$\text{line current} = \frac{P}{E \times p.f.} = \frac{60{,}000}{220 \times 0.80} = \frac{60{,}000}{176} = 341\text{ amp.}$$

To ascertain approximately what size wire should be installed, use the approximate single-phase formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 341 \times 400}{12} = 250{,}066\text{ cir. mils.}$$

The next larger standard size wire is 300,000 cir. mils, which will safely carry the current 341 amp. (see Table 306) if the wires are run open. (If they are concealed—rubber insulated—at least a 500,000 cir. mil conductor must be used.)

Referring to Table 306 for a 300,000 cir. mil conductor, 6 in. separation and 60 cycles: *Resistance volts per amp.* = 0.075 and *Reactance volts per amp.* = 0.153, therefore

$$\text{Resistance drop} = \frac{\text{current} \times \text{resistance volts} \times \text{distance}}{1,000} = \frac{341 \times 0.075 \times 400}{1,000} = 10.23 \text{ volts}$$

$$\text{Per cent. of resistance drop} = \frac{10.23}{220} = 4.65 \text{ per cent.}$$

$$\text{Reactance drop} = \frac{\text{current} \times \text{reactance volts} \times \text{distance}}{1,000} = \frac{341 \times 0.153 \times 400}{1,000} = 20.9$$

$$\text{Per cent. of reactance drop} = \frac{20.9}{220} = 9.5 \text{ per cent.}$$

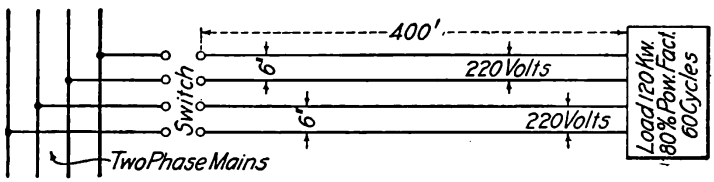


FIG. 154.—Two-phase circuit problem.

Lay out the per cent. resistance and reactance drops on the Mershon diagram (Fig. 158) for 0.80 power factor, as suggested in the single-phase problem above and as illustrated in Fig. 155. The last point on the lay out is between the 9 per cent. and the 10 per cent. volts loss circles in the diagram indicating that the volts loss with 300,000 cir. mil conductors would be about 9½ per cent. The allowable loss is but 5 per cent., so a different size conductor must be selected.

A conductor larger than 300,000 cir. mils might be selected that would bring the volts line loss within the 5 per cent. limit, but it is probably better to install two two-phase transmissions of smaller wire in multiple as shown in Fig. 156, making the aggregate area of the two conductors in multiple equal to about 300,000 cir. mils. (See Paragraph 292.)

Therefore try two transmissions of No. 00 wire. Take values for No. 00 wire from Table 306 in the manner as before, for 60 cycles and a 6 in. separation, remembering that half the former current will flow in the conductors of the subdivided transmission. Then for each two-phase, two-wire circuit the current will be $\frac{1}{2} \times 341 = 170.5$ amp. Therefore:

$$\text{Resistance drop} = \frac{\text{current} \times \text{resistance volts} \times \text{distance}}{1,000} = \frac{170.5 \times 0.156 \times 400}{1,000} = 10.7 \text{ volts}$$

$$\text{Per cent. of resistance drop} = \frac{10.7}{220} = 4.8 \text{ per cent.}$$

$$\text{Reactance drop} = \frac{\text{current} \times \text{reactance volts} \times \text{distance}}{1,000} = \frac{170.5 \times 0.172 \times 400}{1,000} = 11.7 \text{ volts}$$

$$\text{Per cent. of reactance drop} = \frac{11.7}{220} = 5.3 \text{ per cent.}$$

Laying the per cent. resistance and per cent. reactance drops out on the Mershon diagram at 0.80 power factor it will be found that for this No. 00

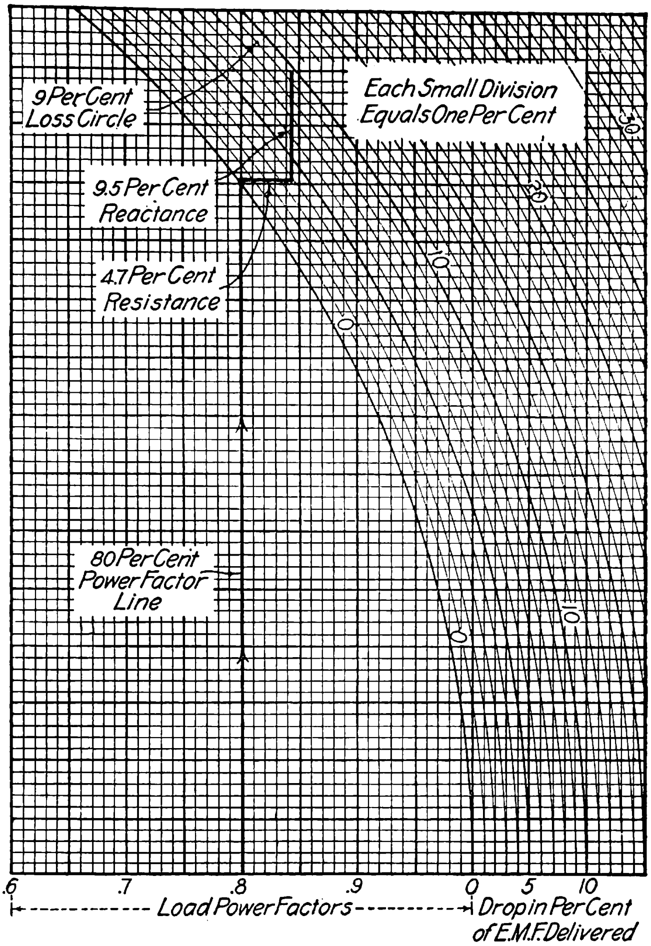


FIG. 155.—Illustrating the application of the Mershon diagram for computing a two-phase, four-wire alternating-current circuit.

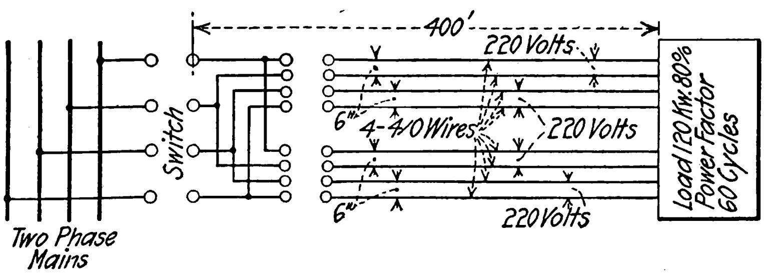


FIG. 156.—Divided two-phase circuit.

wire the per cent. volts line loss will be about 7 per cent., which is excessive.

Making another trial, considering this time two two-phase transmissions of No. 0000 wire in parallel, it will be found that the per cent. volts line loss will be about just a trifle over 5 per cent. So two two-phase circuits in parallel of No. 0000 wire would be used as shown in Fig. 156.

This is an unusually tedious problem and was selected to indicate the method of dividing a given transmission into two transmissions of smaller wire to decrease the effect of line reactance. In practice it might not be the most economical method to install the transmission as indicated in Fig. 156.

302. Calculation of a Three-phase, Three-wire Alternating-current Circuit where Line Reactance must be Considered.—Use the Mershon diagram (Fig. 158). Calculate a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size and distance between centers as obtained for the single-phase circuit. See paragraph 300 for the calculation of a single-phase circuit.

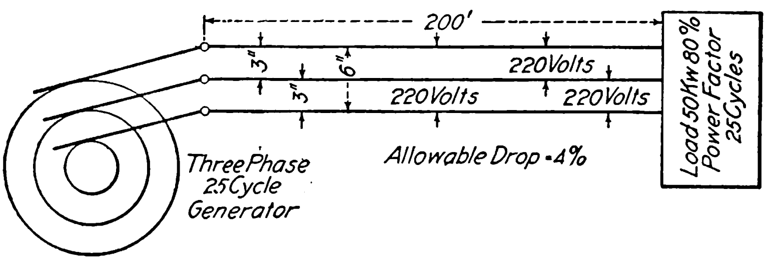


FIG. 157.—Three-phase circuit.

Example.—What size conductor should be used for the open-wire transmission shown in Fig. 157, the allowable volts loss in the line being 4 per cent. or $0.04 \times 220 = 8.8$ volts? Receiver voltage = 220; load = 50 kw.; power factor = 0.80; distance = 200 ft.; distance between wires = 3 in. Frequency is 25 cycles.

Solution.—The actual current in each wire must be known to insure that a conductor large enough to carry it will be selected. (See Par. 69.)

$$\text{actual current} = \frac{0.58 \times P}{E \times p.f.} = \frac{0.58 \times 50{,}000}{220 \times 0.8} = \frac{29{,}000}{176} = 0.165 \text{ amp.}$$

Now find one-half of the total load and proceed with this load as for a single-phase transmission which will be called the imaginary transmission.

$$\tfrac{1}{2} \text{ total load} = \frac{\text{watts}}{2} = \frac{50{,}000}{2} = 25{,}000 \text{ watts}$$

The current in the imaginary transmission would be:

$$I = \frac{P}{E \times p.f.} = \frac{25{,}000}{220 \times 0.80} = \frac{25{,}000}{176} = 142 \text{ amp. in the imaginary transmission.}$$

To approximate the size of wire, use the single-phase formula:

$$\text{cir. mils} = \frac{22 \times I \times L}{V} = \frac{22 \times 142 \times 200}{8.8} = \frac{624{,}800}{8.8} = 71{,}000 \text{ cir. mils.}$$

The next larger standard size wire is No. 1—83,690 cir. mils.—which will safely carry, when exposed, 150 amp. The actual current is 165 amp. No. 1 is therefore not satisfactory from a current-carrying standpoint. Therefore, it will be necessary to use at least the next larger size wire, No. 0, which will safely carry, when exposed, 200 amp. Now check this No. 0 wire for volts line drop (volts line loss).

The average distance between the three wires $= \frac{3 \text{ in.} + 3 \text{ in.} + 6 \text{ in.}}{3} = \frac{12 \text{ in.}}{3} = 4$ in.

Refer to Table 307 under 25 cycles and opposite No. 0 wire and find: Resistance volts per 1,000 ft. = 0.196 and (under 4 in. separation) reactance volts per 1,000 ft. = 0.066. Then

$$\text{Resist. drop} = \frac{\text{current} \times \text{resist. volts} \times \text{dist.}}{1{,}000} = \frac{142 \times 0.196 \times 200}{1{,}000} = 5.57 \text{ volts.}$$

$$\text{Per cent. resistance drop} = \frac{5.57}{220} = 2.5 \text{ per cent.}$$

$$\text{React. drop} = \frac{\text{current} \times \text{react. volts} \times \text{dist.}}{1{,}000} = \frac{142 \times 0.066 \times 200}{1{,}000} = 1.87 \text{ volts.}$$

$$\text{Per cent. reactance drop} = \frac{1.87}{220} = 0.85 \text{ per cent.}$$

Laying out the per cent. resistance drop and the per cent. reactance drop on the Mershon diagram (Fig. 158) at the upper end of the 80 per cent. power factor line as described under the single-phase problem of **300** the last point of the lay out comes just under the 3 per cent. volts loss circle. Therefore the true volts loss in the line will be somewhat less than 3 per cent. with No. 0 wire. Therefore use three No. 0 wires for the transmission as shown in Fig. 157. Study the examples of **300** and **301** for other features of the Mershon diagram method.

303. How to Use the Mershon Diagram (*Westinghouse Electric Co.*).—By means of tables **306** and **307** calculate the resistance-volts and the reactance-volts in the line, and find what per cent. each is of the e.m.f. delivered at the end of the line. Starting from the point on the chart (Fig. 158) where the vertical line corresponding with power factor of the load intersects the smallest circle, lay off in per cent. the resistance e.m.f. horizontally and to the right; from the point thus obtained lay off upward in per cent. the reactance e.m.f. The circle on which the last point falls gives the drop in per cent. of the e.m.f. delivered at the end of the line. Every tenth circle arc is marked with the per cent. drop to which it corresponds.

304. Power Loss in Any Conductor.—Taking 11 ohms as the resistance of a circular mil-foot of commercial copper wire at 75 deg. fahr. the power loss in any conductor may be found thus:

$$P = \frac{11 \times I^2 \times L}{\text{cir. mils}}$$

Wherein, P = power lost in the conductor in watts; I = the current in amperes in the conductor; L = length of the conductor in feet, and cir. mils = area of the conductor in circular mils.

305. Power Loss in a Circuit.—It follows from the above formula that: For a two-wire, direct-current or a single-phase circuit:

$$P = \frac{2 \times 11 \times I^2 \times L}{\text{cir. mils}} = \frac{22 \times I^2 \times L}{\text{cir. mils}}$$

For a balanced four-wire, two-phase circuit:

$$P = \frac{4 \times 11 \times I^2 \times L}{\text{cir. mils}} = \frac{44 \times I^2 \times L}{\text{cir. mils}}$$

For a balanced three-wire, three-phase circuit:

$$P = \frac{3 \times 11 \times I^2 \times L}{\text{cir. mils}} = \frac{33 \times I^2 \times L}{\text{cir. mils}}$$

Wherein, P = the power, in watts, lost in the line; I = the current in amperes which flows in each of the wires of the line; L = the length or single distance of the circuit and cir. mils = area in circular mils of each of the wires of the line. The above formulas can be used only when all of the wires of the line are the same size.

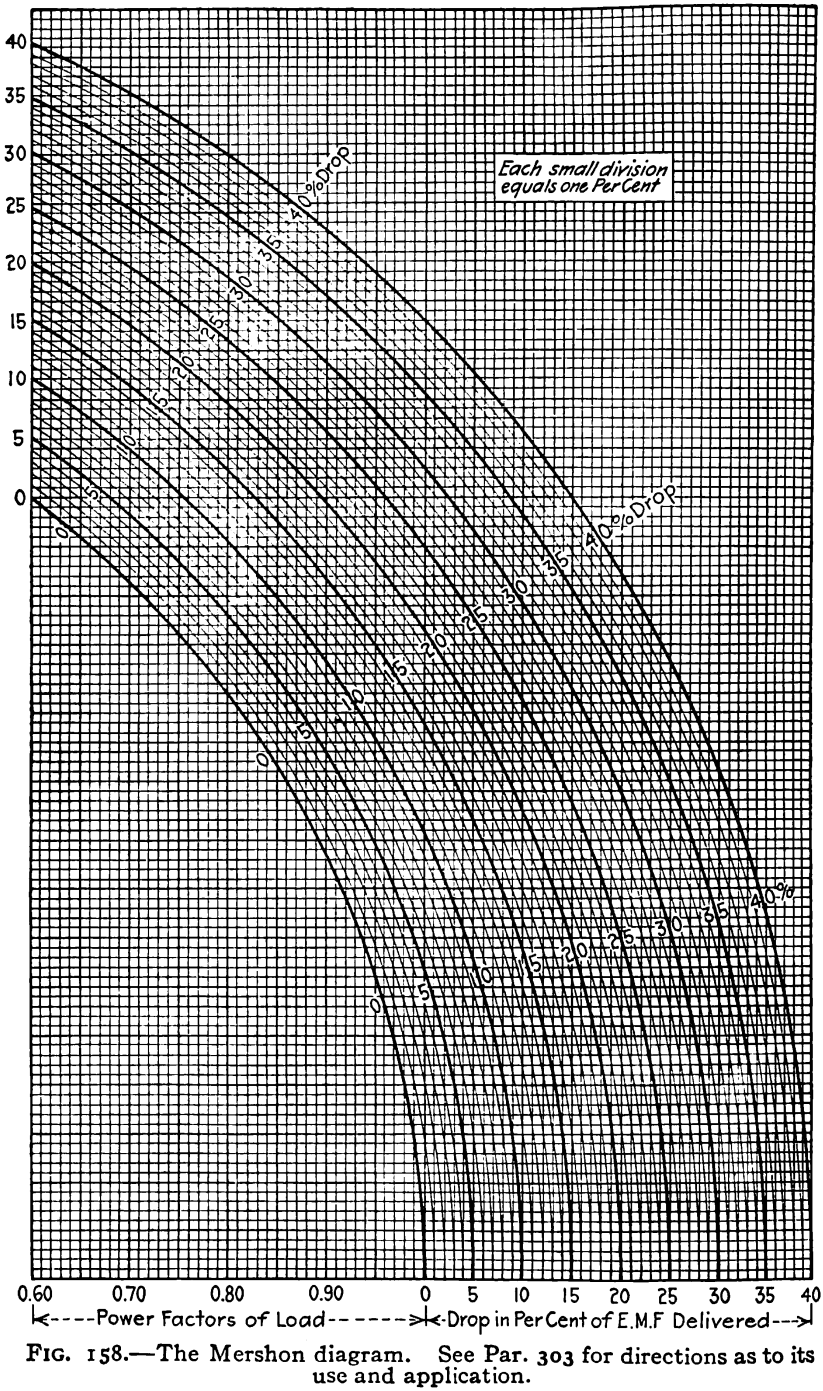


FIG. 158.—The Mershon diagram. See Par. 303 for directions as to its use and application.

306. Table for Calculating Drop in Alternating-current Lines with the Mershon Diagram—60 Cycles

Size of wire (cir. mils) and B. & S. gage	Safe carrying capacity, N.E.C. 1915 Rules: Rubber ins., amp., Table A	Safe carrying capacity, N.E.C. 1915 Rules: Other ins., amp., Table B	Resistance-volts in 1,000 ft. of copper line (2,000 ft. of wire) for 1 amp. (The values in this column are really the resistances of 2,000 ft. of conductor at 75 deg. fahr.)	[1]Frequency = 60 cycles. Reactance-volts in 1,000 ft. of line (2,000 ft. of wire) for 1 amp. at 7,200 alternations per minute (60 cycles per second) for the distance given in inches between centers of conductors. (The values in these columns are really the reactances of 2,000 ft. of conductor)										
				½	1	2	3	4	5	6	9	12	18	24
14– 4,107	15	20	5.06	0.138	0.178	0.218	0.220	0.233	0.244	0.252	0.271	0.284	0.302	.....
12– 6,530	20	25	3.18	0.127	0.159	0.190	0.210	0.223	0.233	0.241	0.260	0.273	0.292	.....
10–10,380	25	30	2.00	0.116	0.148	0.180	0.199	0.212	0.223	0.221	0.249	0.262	0.281	.....
8–16,510	35	50	1.26	0.106	0.138	0.169	0.188	0.201	0.212	0.220	0.238	0.252	0.270	0.284
6–26,250	50	70	0.790	0.095	0.127	0.158	0.178	0.190	0.210	0.209	0.228	0.241	0.260	0.272
4–41,740	70	90	0.498	0.085	0.117	0.149	0.167	0.180	0.190	0.199	0.217	0.230	0.249	0.262
2–66,370	90	125	0.312	0.074	0.106	0.138	0.156	0.169	0.180	0.188	0.206	0.220	0.238	0.252
1–83,690	100	150	0.248	0.068	0.101	0.132	0.151	0.164	0.174	0.183	0.201	0.214	0.233	0.246
0–105,500	125	200	0.196	0.063	0.095	0.127	0.145	0.159	0.169	0.177	0.196	0.209	0.228	0.241
2/0–133,100	150	225	0.156	0.057	0.090	0.121	0.140	0.153	0.164	0.172	0.190	0.204	0.222	0.236
3/0–167,800	175	275	0.122	0.052	0.085	0.116	0.135	0.148	0.158	0.167	0.185	0.199	0.217	0.230
4/0–211,600	225	325	0.098	0.046	0.079	0.111	0.130	0.143	0.153	0.161	0.180	0.193	0.212	0.225
250,000	240	350	0.085	.....	0.075	0.10[illegible]	0.125	0.139	0.148	0.157	0.175	0.189	0.207	0.220
300,000	275	400	0.075	.....	0.071	0.103	0.120	0.134	0.144	0.153	0.171	0.185	0.203	0.217
350,000	300	450	0.061	.....	0.067	0.099	0.118	0.128	0.141	0.149	0.168	0.182	0.200	0.213
400,000	325	500	0.052	.....	0.064	0.096	0.114	0.127	0.138	0.146	0.165	0.178	0.197	0.209
500,000	400	600	0.042	.....	.....	0.090	0.109	0.122	0.133	0.141	0.160	0.172	0.192	0.202
600,000	450	680	0.035	.....	.....	0.087	0.106	0.118	0.128	0.137	0.155	0.169	0.187	0.200
700,000	500	760	0.030	.....	.....	0.083	0.102	0.114	0.125	0.133	0.152	0.165	0.184	0.197
800,000	550	840	0.026	.....	.....	0.080	0.099	0.112	0.122	0.130	0.148	0.162	0.181	0.194
900,000	600	920	0.024	.....	.....	0.077	0.096	0.109	0.119	0.127	0.146	0.159	0.178	0.191
1,000,000	650	1,000	0.022	.....	.....	0.075	0.094	0.106	0.117	0.125	0.144	0.158	0.176	0.188

[1] For other frequencies the reactance will be in direct proportion to the frequency.

307. Table for Calculating Drop in Alternating-current Lines with the Mershon Diagram—25 Cycles

Size of wire (cir. mils) and B. & S. gage	Safe carrying capacity, N.E.C. 1915 Rules		Resistance-volts in 1,000 ft. of copper line (2,000 ft. of wire) for 1 amp. (The values in this column are really the resistances of 2,000 ft. of conductor at 75 deg. fahr.)	[1] Frequency = 25 cycles Reactance-volts in 1,000 ft. of line (2,000 ft. of wire) for 1 amp. at 3,000 alternations per minute (25 cycles per second) for the distance given in inches between centers of conductors. (The values in these columns are really the reactances of 2,000 ft. of conductor)										
	Rubber ins., amp., Table A	Other ins., amp., Table B		½	1	2	3	4	5	6	9	12	18	24
14- 4,107	15	20	5.06	0.057	0.071	0.084	0.093	0.097	0.102	0.105	0.113	0.118	0.126	.....
12- 6,530	20	25	3.18	0.053	0.066	0.080	0.087	0.094	0.097	0.101	0.108	0.113	0.122	.....
10-10,380	25	30	2.00	0.049	0.062	0.075	0.083	0.088	0.092	0.096	0.104	0.110	0.117	.....
8-16,510	35	50	1.26	0.044	0.057	0.071	0.078	0.084	0.088	0.092	0.099	0.105	0.113	.....
6-26,250	50	70	0.790	0.040	0.053	0.066	0.074	0.079	0.084	0.087	0.095	0.100	0.108	.....
4-41,740	70	90	0.498	0.035	0.049	0.062	0.070	0.075	0.079	0.083	0.091	0.096	0.104	.....
2-66,370	90	125	0.312	0.031	0.044	0.057	0.065	0.071	0.075	0.078	0.086	0.092	0.099	.....
1-83,690	100	150	0.248	0.028	0.042	0.055	0.063	0.068	0.073	0.076	0.083	0.089	0.097	.....
0-105,500	125	200	0.196	0.026	0.040	0.053	0.061	0.066	0.070	0.073	0.082	0.087	0.095	.....
2/0-133,100	150	225	0.156	0.024	0.037	0.051	0.058	0.064	0.068	0.072	0.079	0.085	0.093	.....
3/0-167,800	175	275	0.122	0.022	0.035	0.048	0.056	0.062	0.066	0.070	0.077	0.083	0.091	.....
4/0-211,600	225	325	0.098	0.019	0.033	0.046	0.053	0.059	0.064	0.067	0.075	0.081	0.088	.....
250,000	240	350	0.085	.....	0.031	0.044	0.051	0.058	0.062	0.065	0.073	0.079	0.086	0.092
300,000	275	400	0.075	.....	0.030	0.043	0.050	0.056	0.060	0.064	0.071	0.077	0.084	0.090
350,000	300	450	0.061	.....	0.028	0.041	0.049	0.054	0.059	0.062	0.070	0.076	0.083	0.089
400,000	325	500	0.052	.....	0.027	0.040	0.048	0.053	0.057	0.061	0.069	0.075	0.082	0.087
500,000	400	600	0.042	.....	.....	0.038	0.046	0.051	0.055	0.059	0.067	0.072	0.080	0.085
600,000	450	680	0.035	.....	.....	0.036	0.044	0.049	0.053	0.057	0.065	0.070	0.078	0.083
700,000	500	760	0.030	.....	.....	0.035	0.042	0.048	0.052	0.056	0.063	0.069	0.077	0.082
800,000	550	840	0.026	.....	.....	0.033	0.041	0.047	0.050	0.054	0.062	0.068	0.075	0.081
900,000	600	920	0.024	.....	.....	0.032	0.040	0.046	0.050	0.053	0.061	0.066	0.074	0.080
1,000,000	650	1,000	0.022	.....	.....	0.031	0.039	0.044	0.049	0.052	0.060	0.065	0.073	0.079

[1] For other frequencies the reactance will be in direct proportion to the frequency.

308. The Question of Energy Loss in a Circuit should not be Slighted in Circuit Calculations (*Standard Handbook*).—It is well known that in overcoming resistance, electrical energy is wasted; and as it costs money to develop or buy electrical energy, it is evident that in any commercial system such waste must be kept to a minimum. This may be done by decreasing the resistance of the conductors or what amounts to the same thing, of increasing the size of the conductors. Inasmuch as this is also an expensive matter, care must be exercised that the additional sum added to the expenditure in copper is not so excessive as to more than counterbalance the cost of the energy continually saved. It has been laid down as a general rule that for the transmission of any given energy, the most economical conductor is one having such a resistance that the value of the energy wasted in heat annually is equal to the interest per annum on the original outlay upon the conductor.

Knowing the average amount of energy to be transmitted, it becomes an easy matter to find the average kilowatt-hours wasted in a conductor of a given resistance. The question of energy loss in conductors increases in importance as the price of the energy increases, and decreases as the price of energy decreases, so that where the energy costs or may be purchased for very little, the loss may be more than offset by the additional investment in copper necessary to avoid it. With regard to the conductors themselves, in interior wiring work, it is merely a question of the additional cost of the copper, as the price of the installation, etc., is usually about the same for any size conductor that is apt to be used. So many considerations enter into the question of the best size of wire to employ consistent with strict economy, that the matter cannot be discussed at length here. A few illustrations may suffice to show what an important bearing the question has in wiring work.

Example.—A two-wire direct-current feeder system supplies a current of 50 amp. at a distance of 200 ft. from the meter. The drop allowed is 5 per cent. and the voltage of the circuit is 110. What size of wire should be installed?

Solution.—Substituting the value given above in the cir. mil. formula, the size of wire is found to be

$$A = \frac{22 \times 50 \times 200}{110 \times 0.05} = 40{,}000 \text{ cir. mils, or a No. 4 wire.}$$

If this energy were used 10 hr. a day for 300 days, and the cost of the energy were 8 cents per kilowatt-hour, the total yearly cost would be

$$\frac{50 \times 110 \times 10 \times 300 \times 0.08}{1{,}000} = \$1{,}320.$$

Of this 5 per cent., or $66, would be lost yearly due to the drop. The cost of 400 ft., No. 4, double-braid, rubber-covered wire would be about $22.50. The interest at 5 per cent. on this $22.50 would be $1.13. Since the yearly cost of energy lost is $66.00, it would cost each year $1.13 + $66.00 = $67.13 to operate this No. 4 conductor, assuming that the use of money costs 5 per cent. a year. It is evident, since the interest charge is so much smaller than the energy cost charge, that a No. 4 conductor is not nearly large enough and that it is not by any means the most economical one for the condition of the problem.

Table 310 shows the total annual charges or costs for conductors of several sizes worked out for the conditions of this problem, it being assumed that, in each case, the current of 50 amp. flows 10 hr. a day, 300 days a year over a conductor length of 400 ft., the energy cost being 8 cents a kw-hr. and the costs of the conductors being those indicated. As above noted the voltage drop for the No. 4 conductor is 5 per cent. For the No. 6 conductor

(which will safely carry only 46 amp. and which therefore would be too small for the 50 amp. of this problem) it will be greater than 5 per cent. For conductors larger than No. 4 the drop will be less than 5 per cent.

It is evident from Table 310 that, for the conditions of this problem and with wire at the prices assumed, a 400,000 c. m. conductor is the most economical, that is, it has the least *total annual cost*, although a 300,000 c. m. conductor is almost as economical.

The market price of copper has a bearing on the matter of conductor economy. Where the energy cost is very low, the conductor that would be theoretically the most economical might be too small to safely carry the current. In such a case, the most economical conductor that can be used is the smallest one that has ample carrying capacity.

Example.—A two-wire feeder system 100 ft. long supplies a device requiring a current of 500 amp. The voltage of the supply is 110 and a drop of 1 per cent. is permitted. Required the size of wire (slow-burning weatherproof wire being permitted) used.

Solution.—Calculating the size of wire as in the preceding case shows that a 1,100,000-cir. mil cable is required.

If the energy in this case costs 2 cents per kilowatt-hour and the device were used 24 hr. a day and 300 days a year, what size of wire should be installed to obtain the best economy?

With the above data the yearly cost of the energy used is found to be

$$\frac{24 \times 300 \times 500 \times 110 \times 0.02}{1,000} = \$7,920.$$

If a 2,500,000-cir. mil cable be used, the drop according to the formula would be approximately 0.44 volt or 0.4 per cent. ($\frac{4}{10}$ per cent). The weight of 200 ft. of cable equivalent to 2,500,000 cir. mils would be approximately 1,900 lb., and assuming the cost to be 30 cents per pound, the copper investment would be $570. The interest on this investment at 5 per cent. would be $28.50. Now a loss of 0.4 per cent. on $7,920 would be $32 per year and since the interest on the copper investment is less than that amount, the 2,500,000-cir. mil cable should be installed. A 3,000,000-cir. mil cable would be found to be a trifle too costly. The substitution of the 2,500,000-cir. mil cable for the 1,000,000-cir. mil cable results therefore in a saving of $47 yearly. These results are figured on the ground that all other costs remain the same, which may or may not be the case. If copper were cheaper than specified, a larger cable could be substituted with a still further saving. It may readily be seen therefore that the question of drop alone should not determine the size of wire.

The preceding remarks deal with the question of energy loss from a purely financial basis. There are electrical considerations which must be taken into account in determining the maximum drop and energy loss allowable. The variation in the life and candle-power of incandescent lamps and the performance of motors and other equipment as affected by voltage and therefore energy loss should be considered.

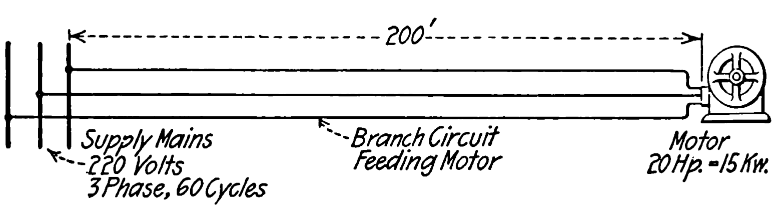


FIG. 159.—Three-phase motor circuit.

309. Use of Constants in Circuit Calculations.—Wiring and many other calculations that involve the use of several constants can be much simplified by resolving the constants into a factor which is itself a constant. It frequently occurs in central-station work that the permissible voltage drop and the power factor remain the same for many wiring computations. These and other constants can be effectively incorporated into a multiplier. An example will best explain the method.

Example.—Consider the problem suggested in Fig. 159. A three-phase 220-volt, 60-cycle, 20-h.p. motor is to be installed. It is assumed that the power factor is 70 per cent. What is the current in the line wires?

The following formula gives the current in each of the wires of a balanced three-phase circuit: $I = P \div 1.73 \times E \times p.f.$ where I is the current in amperes, P is the power transmitted in watts, 1.73 is a constant, E is the voltage of the supply circuit and $p.f.$ is the power factor of the circuit. For wiring calculations it may often be assumed that the factors 1.73, E and $p.f.$ are always of the same value in many computations. These three factors can therefore be resolved into a constant thus: $I = P \div 1.73 \times 220 \times 0.7 = 0.003{,}754 \times P$ watts or approximately: $I = 3.8$ kw.

It is apparent, then, that by multiplying the kilowatt capacity of the motor by the factor 3.8 the approximate full-load current in amperes flowing to the motor will result. The current for the motor of Fig. 159 will be $3.8 \times 15 = 57$ amp. Other problems may be much simplified by resolving constants into a factor.

309A. Allowable Amperes for 1-volt Drop (*National Lamp Works*)

Size wire, B. & S. or A.W.G.	Length of circuit in feet (length of wire twice as great)																
	15	20	30	40	60	80	100	125	150	175	200	250	300	350	400	450	500
16	8.3	6.2	4.2	3.1	2.1	1.6	1.2	1.0	0.8	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.2
14	13	9.9	6.6	5.0	3.3	2.5	2.0	1.6	1.3	1.1	1.0	0.8	0.7	0.6	0.5	0.4	0.4
12	21	16	10	7.9	5.3	3.9	3.1	2.5	2.1	1.8	1.6	1.3	1.1	0.9	0.8	0.7	0.6
10	33	24	17	13	8.3	6.3	5.0	4.0	3.3	2.9	2.5	2.0	1.7	1.4	1.3	1.1	1.0
8	53	40	27	20	13	10	8.0	6.4	5.3	4.6	4.0	3.2	2.7	2.3	2.0	1.8	1.6
6	84	63	42	32	21	16	13	10	8.5	7.2	6.3	5.1	4.2	3.6	3.2	2.8	2.5
4	134	101	67	50	34	25	20	16	13	12	10	8.1	6.7	5.8	5.0	4.5	4.0
3	169	127	84	63	42	32	25	20	17	15	13	10	8.5	7.2	6.3	5.6	5.1
2	216	160	107	80	53	40	32	26	21	18	16	13	11	9.2	8.0	7.1	6.4
1	268	201	134	101	67	50	40	32	27	23	20	16	13	12	10	9.0	8.1
0	340	254	167	128	85	64	51	41	34	29	25	20	17	15	13	11	10

A Prohibited by "allowable" current-carrying capacity" rule.

B Prohibited by "660 watts per circuit" rule. (See Sec. 4, Par. **248**.)

C Not prohibited

Explanation.—Values in Section *A* of table are greater than those permitted by the *Code* (Par. **167**) in rubber-insulated copper wires of the sizes shown. Values in both Sections *A* and *B* are all such that, in any circuit operating at 110 volts or more, they will constitute a load greater than 660 watts, which is prohibited on ordinary incandescent-lamp branch circuits (Sec. 4, Par. **248**). Values in Section *C* are not prohibitive.

Example.—It is desired to install a circuit 80 ft. in length (160 ft. of wire). Reading down column headed "80," a current of 2.5 amp. causes a drop of 1 volt in an 80-ft. circuit of No. 14 wire. In an 80-ft. circuit of No. 12 wire, 3.9 amp. would cause 1 volt drop; with No. 10 wire, 6.3 amp. would cause 1 volt drop. For a current of 6 amp.—the max. current permitted on a 110-v., incandescent-lamp, branch circuit—a No. 10 wire should be used to keep the drop in this 80-ft. circuit within a 1-volt limit.

310. Table Showing Relative Economies of Conductors of Different Sizes.

(*This table applies only to the first example in paragraph* 308)

	No. 6 wire	No. 4 wire	250,000 c. m.	300,000 c. m.	400,000 c. m.	500,000 c. m.	600,000 c. m.	700,000 c. m.
Cost of 400 ft. of conductor....................	$16.80	$22.50	$102.40	$118.40	$150.40	$184.00	$218.20	$248.00
Interest on above cost at 5 per cent............	$0.84	$1.13	$5.12	$5.92	$7.52	$9.20	$10.91	$12.40
Cost of energy lost in conductor at 8 cents per kw-hr.	$101.64	$66.00	$10.56	$8.84	$6.60	$5.28	$4.49	$3.96
Total annual cost of conductor................	$102.48	$67.13	$15.68	$14.76	$14.12	$14.48	$15.40	$16.36

311. Table for Three-phase Transmission (*General Electric Co.*)

(Approximate distances over which 100 kw., three-phase current, can be transmitted with different sizes of wires at different voltages, assuming an energy loss of 10 per cent. and a power factor of 85 per cent.)

American or B. & S.	Area in circular mils	Distance of transmission for various voltages at receiving end—miles				
		2,000 v	3,000 v	4,000 v	5,000 v	6,000 v
6	26,250	1.32	2.98	5.28	8.27	11.92
5	33,100	1.66	3.75	6.64	10.40	15.00
4	41,740	2.10	4.74	8.40	13.15	18.96
3	52,630	2.54	5.96	10.16	16.55	23.84
2	66,370	3.33	7.51	13.32	20.85	30.04
1	83,690	4.21	9.48	16.84	26.32	37.92
0	105,500	5.29	11.92	21.16	33.10	47.68
00	133,100	6.71	15.11	26.84	41.97	60.44
000	167,800	8.45	19.04	33.80	52.85	76.16
0000	211,600	10.62	23.92	42.48	66.42	95.68
	250 000	12.58	28.33	50.32	78.67	113.32
	500,000	25.17	56.66	100.68	157.35	226.64

Example.—What size wire is required to deliver 500 kw. at 6,000 volts a distance of 12 miles; energy loss, 10 per cent.; power factor, 85 per cent.?

Solution.—To transmit 100 kw. one would look in the 6,000-volt column for value nearest to 12 miles and use size of wire corresponding. To transmit five times this power or 500 kw., find the value corresponding most closely to $5 \times 12 = 60$ miles in the 6,000-volt column. Nearest value is 60.44 miles, which corresponds to No. 00 wire. No. 00 is the size required. To ascertain wire size to give a 5 per cent. loss—one-half the loss for which table is computed—multiply the distance of transmission by 2 before finding wire size.

SECTION II

GENERATORS AND MOTORS

PRINCIPLES, CHARACTERISTICS AND MANAGEMENT OF DIRECT-CURRENT MOTORS AND GENERATORS

1. **Direct-current generators** develop a direct or continuous e.m.f., that is, one that is always in the same direction. Commercial direct-current generators have commutators and may thereby be distinguished from alternating-current machines. The function of the commutator and the elementary ideas of generation of e.m.f. and of commutation are discussed in the First Section. See Index. Additional information in regard to commutation as applied to direct-current motors, which is in general true for direct-current generators, is given hereinafter.

2. **Excitation of Generator Fields.**—To generate an e.m.f. conductors must cut a magnetic field which in commercial machines must be relatively strong. A permanent magnet can be used for producing such a field in a generator of small output, such as a telephone magneto or a generator for sparking for an automobile; but for generators for light and power the field is produced by electro-magnets, which may be excited by the machine itself or "separately excited" from another source.

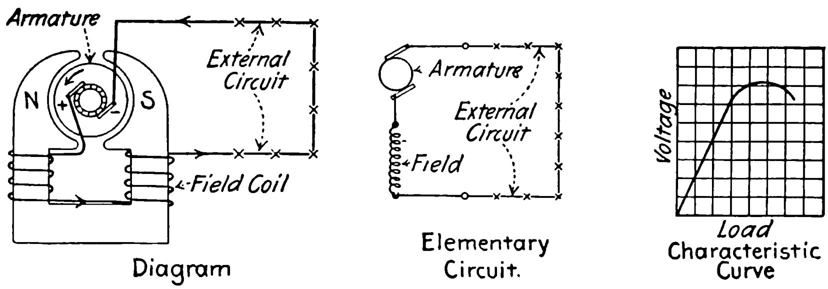


FIG. 1.—Series generator diagrams.

3. **Series-wound or constant-current generators** have their armature coils, field coils and external circuits in series with one another. (See Fig. 1.) Series generators are now used commercially only for series arc-lighting circuits and are equipped with automatic regulators to maintain the current constant irrespective of the resistance of the external circuit, *i.e.*, the number of lamps in service. The same current passes through each lamp in the series and the generator. The voltage at the brushes of a series machine is equal to (neglecting a small line loss) the voltage per lamp times the number of lamps. Thus on a circuit of 100 lamps each requiring 50 volts the brush pressure would be $100 \times 50 = 5{,}000$ volts. As shown by the curve of Fig. 1 up to a certain maximum value with an increase in load—resistance in this case—the voltage of the generator increases, tending to keep the current

constant. Automatic regulation to maintain constant current is usually effected, commercially, by either shifting the brushes or by cutting in and out portions of the field winding or by a combination of the two methods.

In Fig. 2 are shown the essentials of an arrangement for regulation by brush shifting. The course of the main current is indicated by the heavy line. When the current is at normal value the *contactor* is held midway between the contacts C_1 and C_2 by the spring. If the current increases slightly the core is pulled down into *solenoid* and brings the *contactor* with it, which makes contact with C_2. This permits a small current in shunt with the solenoid to flow through the *clutch B*, the mechanical details of which are not shown. This *clutch* pulls the *shifting rod* down and so shifts the brushes as to tend to maintain the current at a constant value. A decrease in current allows the spring to pull the *contactor* against C_1; *clutch A* operates and the brushes are shifted in the opposite direction. The principle of an arc-light (constant current) machine that is regulated by field variation is illustrated in Fig. 3. The *lever L* is shifted automatically and cuts in or out turns of the field magnet so as to maintain a constant current in the external circuit.

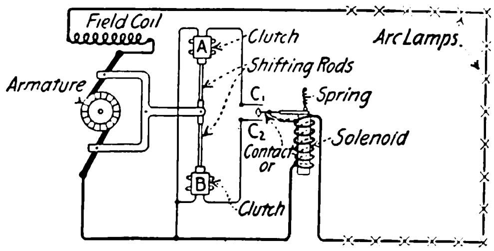


FIG. 2.—Essentials of brush-shifting mechanism for a constant-current generator.

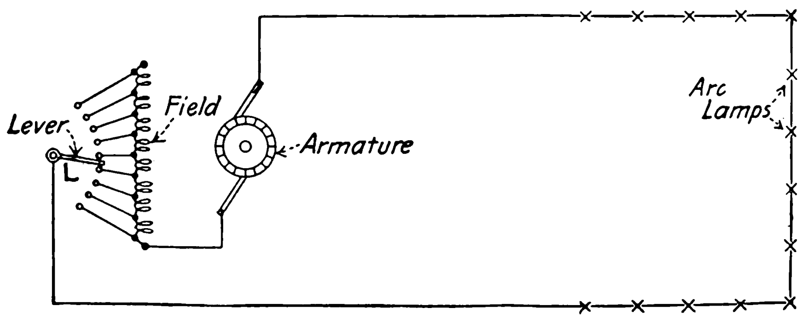


FIG. 3.—Regulation of an arc-lamp machine by field variation.

4. Separately excited generators are used for electro-plating and for other electrolytic work where it is essential that the polarity of a machine be not reversed. Self-excited machines may change their polarities. The essential diagrams are shown in Fig. 4. The fields may be excited from any direct-current constant potential source, such as a storage battery or lighting circuit.

The field magnets can be wound for any voltage because they have no electrical connection with the armature. With a constant field excitation, the voltage will drop slightly from no-load to full-load because of armature drop and armature reaction.

5. **The shunt-wound generator** is shown diagrammatically in Fig. 5. Shunt generators are now seldom used. They have been superseded by compound-wound machines. A small part of the total current, the exciting current, is shunted through the fields. The exciting current varies from possibly 5 per cent. of the total current in small machines to 1 per cent. in large ones. The exciting current is determined by the voltage at the brushes and

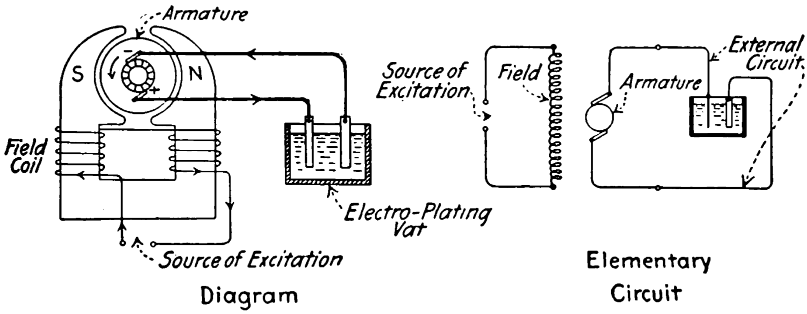


FIG. 4.—Separately excited generator diagrams.

the resistance of the field winding. Residual magnetism in the field cores permits a shunt-generator to "build up." This small amount of magnetism that is retained in the field cores induces a voltage in the armature (Timbie's *Elements of Electricity*). This voltage sends a slight current through the field coils which increases the magnetization. Thus, the induced voltage in the armature is increased. This in turn increases the current in the fields, which still further increases the magnetization, and so on, until the saturation point and normal voltage of the machine are reached. This "building up" action is the same for any self-excited generator and often requires 20 to 30 sec.

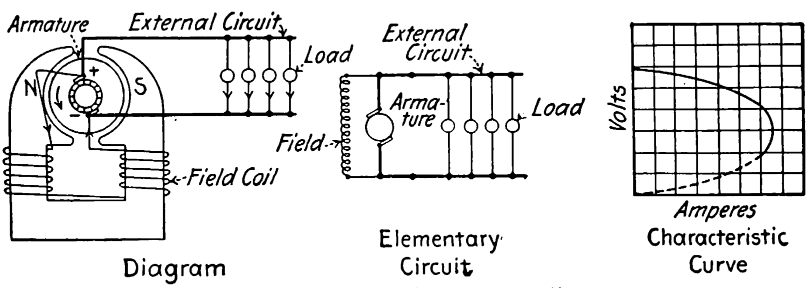


FIG. 5.—Shunt-wound generator diagrams.

If a shunt generator (Timbie) runs at constant speed, as more and more current is drawn from the generator, the voltage across the brushes falls slightly. This fall is due to the fact that it requires more and more of the generated voltage to force this increasing current through the windings of the armature. That is, the armature IR drop increases. This leaves a smaller part of

the total e.m.f. for brush e.m.f., and then when the brush pressure falls, there is a slight decrease in the field current which is determined by the brush pressure. This causes the total e.m.f. to drop a little, which still further lowers the brush potential. These two causes combine to gradually lower the brush pressure (voltage) especially at heavy overloads. The curve in Fig. 5 shows these characteristics. For small loads the curve is nearly horizontal, but at heavy overloads it shows a decided drop. The point where the output of a commercial machine drops off is beyond the operating range and is only of theoretical interest.

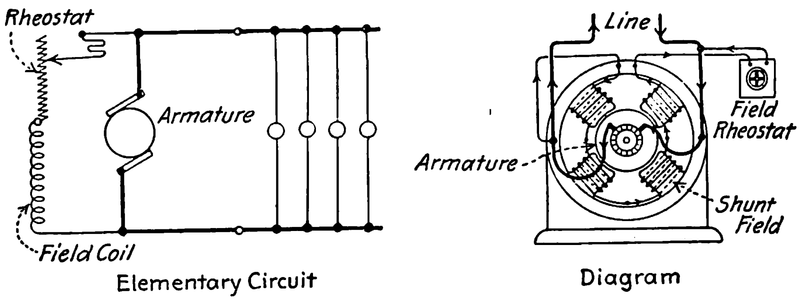


FIG. 6.—Shunt-wound generator with rheostat.

The voltage of a shunt machine may be kept fairly constant by providing extra resistance in the field circuit, see Fig. 6, which may be cut out as the brush potential falls. This will allow more current to flow through the field coils and increase the number of magnetic lines set up in the magnetic circuit. If the speed is kept constant, the armature conductors cut through the stronger magnetic field at the same speed, and thus induce a greater e.m.f. and restore the brush potential to its former value. This resistance may be cut out either automatically or by hand. See *Rheostat*, Index.

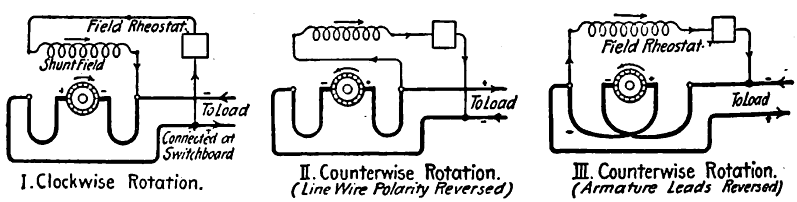


FIG. 7.—Changing rotation direction of shunt machine.

6. A shunt-wound generator gives a fairly constant voltage, even with varying loads, and can be used for incandescent lighting and other constant potential loads. These generators do not operate well in parallel, partially because the voltage of one machine may rise above that of the others and it will run them as motors. Shunt generators running in parallel do not "divide the load" well between themselves. They are seldom installed now, as compound-wound generators are more satisfactory for most purposes. Shunt generators may be bipolar (two poles) or multipolar (more

than two poles) similarly to compound-wound generators. See the following paragraphs.

7. **How to reverse the direction of rotation** of a shunt-wound machine is indicated in Fig. 7. Rotation is *clockwise* when, facing the commutator end of a machine, the rotation is in the direction

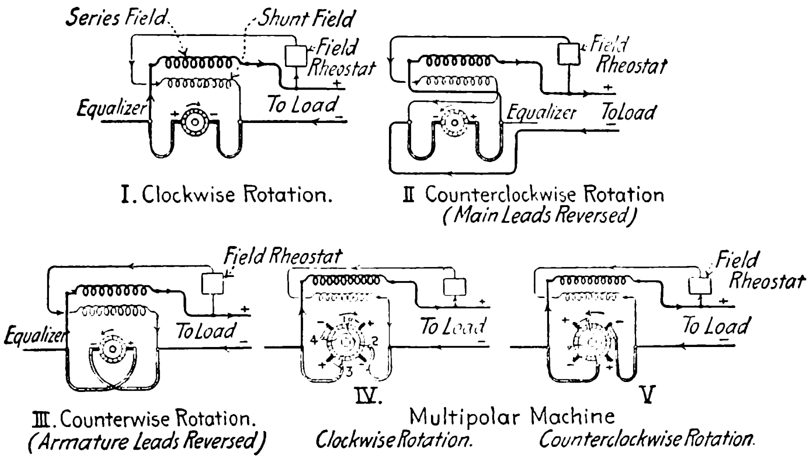


FIG. 8.—Changing rotation direction of compound machine.

of the hands of a clock. *Counter-clockwise* rotation is the reverse. It is desirable, when changing the direction of rotation, not to reverse the direction of current through the field windings. If it is reversed the magnetism developed by the windings on starting will oppose the residual magnetism and the machine may not "build-up." Connections for reversing compound machines are

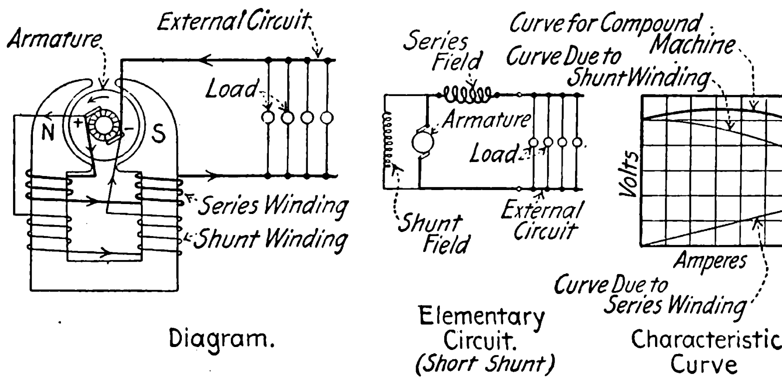


FIG. 9.—Compound-wound generator diagrams.

shown in Fig. 8. A multipolar machine can be reversed as shown by reversing the brushes on the studs and then re-locating them on the neutral points.

8. **The compound-wound generator** is shown diagrammatically in Fig. 9. If a series winding be added to a shunt generator

(Fig. 5), the two windings will tend to maintain a constant voltage as the load increases. The magnetization due to the series windings increases as the line current increases, which will cause the voltage generated by the armature to rise. The drop of voltage at the brushes that occurs in a shunt generator is thus compensated for. See also Figs. 15, 16 and 17.

9. **A flat-compounded generator** is one having its series coils so proportioned that the voltage remains practically constant at all loads within its range.

10. **An over-compounded generator** has its series windings so proportioned that its full-load voltage is greater than its no-load voltage. Over-compounding is necessary where it is desirable to maintain a practically constant voltage at some point out on the line distant from the generator. It compensates for line drop. The characteristic curve (Fig. 9) indicates how the terminal voltage of a compound-wound machine is due to the action of both shunt and series windings. The voltage of the compound generator at any load is equal to the sum of the voltage due to shunt winding plus that due to the series winding. Generators are usually over-compounded so that the full-load voltage is from 5 per cent. to 10 per cent. greater than the no-load voltage.

Although compound-wound generators are usually provided with a field rheostat, it is not intended for regulating voltage as the rheostat of a shunt-wound machine is. It is provided to permit of initial adjustment of voltage and to compensate for changes of the resistance of the shunt winding caused by heating. With a compound-wound generator, the voltage having been once adjusted, the series coils automatically strengthen the magnetic field as the load increases. For direct-current power and lighting work, compound-wound generators are used almost universally.

11. **If a compound-wound generator is short-circuited** the field strength due to the series windings will be greatly increased, but the field due to the shunt winding will lose its strength. For the instant or so that the shunt magnetization is diminishing a heavy current will flow. If the shunt magnetization is a considerable proportion of the total magnetization the current will decrease after the heavy rush and little harm will be done if the armature has successfully withstood the heavy rush. However, if the series magnetization is quite strong in proportion to the shunt, their combined effect may so magnetize the fields that the armature will be burnt out.

12. **A short-shunt compound-wound generator** has its shunt field connected directly across the brushes. (See Fig. 9.) Generators are usually connected in this way because it tends to maintain the shunt field current more nearly constant on variable loads, as the drop in the series winding does not directly affect the voltage on the shunt field with this arrangement.

13. **A long shunt generator** has its shunt field winding connected across the terminals of the generator. (See Fig. 10.)

14. **Three-wire direct-current generators** are discussed, as regards their application to three-wire systems, in the first section. See index. They are ordinary direct-current generators with the

modifications and additions described below. They are usually wound for 125–250 volt three-wire circuits. In commercial three-wire generators (*Westinghouse Electric & Manufacturing Co.*) four equidistant taps are made in the armature winding, and each pair of taps diametrically opposite each other is connected together through a balance coil. (See Fig. 11.) The middle points of the two balance coils (see Index) are connected together and this junction constitutes the neutral point to which the third or neutral wire of the system is connected. A constant voltage is maintained between the neutral and outside wires which, within narrow limits, is one-half the generator voltage. The generator shaft is extended at the commutator end for the collector rings. Four collector brushes and brush-holders are used in addition to the regular direct-current brushes and brush-holders.

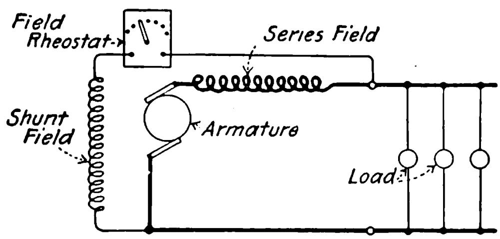


FIG. 10.—Long-shunt compound-wound generator.

15. The series coils of compound-wound three-wire generators are divided into halves (see Fig. 12), one of which is connected to the positive and one to the negative side. This is done to obtain compounding on either side of the system when operating on an unbalanced load. To understand this, consider a generator with the series field in the negative side only and with most of the load on the positive side of the system. The current flows from the positive brush through the load and back along the neutral wire without passing through the series field. The generator is then operating as an ordinary shunt machine. If most of the load be on the negative side, the current flows out the neutral wire and back through the series fields, boosting the voltage (on that side only). Such operation is evidently not satisfactory, and so the divided series fields are provided.

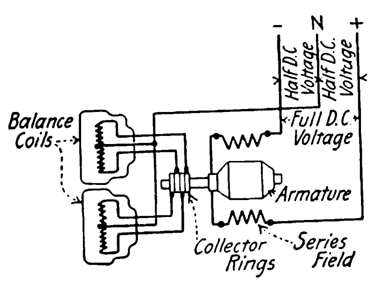


FIG. 11.—Diagram showing connections for three-wire generator.

16. As there are two series fields, two equalizer buses are required when several three-wire machines are installed (see Fig. 12) and are to be operated in multiple. The two equalizers serve to distribute the load equally between the machines and to prevent cross currents due to differences in voltage on the different generators. Because of the equalizer connections, two small terminal boards are supplied, one for each side of the generator. Arrangement is also made for ammeter shunts on the terminal boards.

An ammeter shunt is mounted directly on each of the contact boards of the machine. The total current output of the machine

can thereby be read at the switchboard. As the shunts are at the machine, there is no chance for current to leak across between generator switchboard leads without causing a reading on the ammeters. Two ammeters must be provided for reading the current in the outside wires. It is important that the current be measured on both sides of the system, for with an ammeter in one side of the system only, it is possible for a large unmeasured current to flow in the other side with disastrous results.

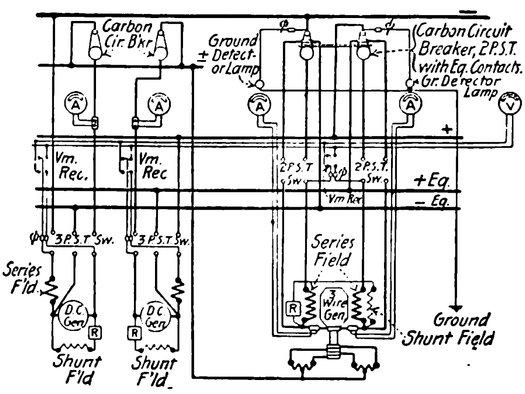


FIG. 12.—One three-wire direct-current generator, 125–250 volts, in parallel with two two-wire generators, 125 volts. Diagram of connections.

17. Wires connecting the balance coils to a three-wire generator must be short and of low resistance. Any considerable resistance in these will affect the voltage regulation. The unbalanced current flows along these connections; consequently, if they have much resistance, the resulting drop in voltage reduces the voltage on the heavily loaded side.

Switches are ordinarily not placed in the circuits connecting the four collector rings to the balance coils. When necessary, the coils may be disconnected from the generator by raising the brushes from the collector rings. Switching arrangements often make it necessary to run the balance-coil connections to the switchboard and back, requiring heavy leads to keep the drop low; or if heavy leads are not used, then poor regulation may result. The balance coils are so constructed that there is very little likelihood of anything happening to them that will not be taken care of by the main circuit breakers. Complete switchboard connection diagrams are given in Figs. 12, 13 and 14.

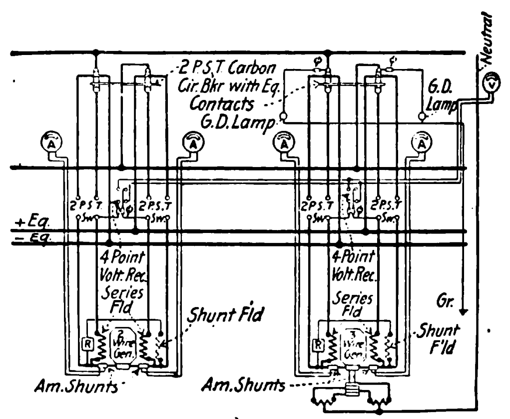


FIG. 13.—One three-wire direct-current generator, 125–250 volts, in parallel with one two-wire generator, 250 volts. Diagram of connections.

18. To Start a Shunt-wound Generator.—Note the directions in 21 concerning the oiling arrangements and bringing the machine up to speed. (1) See that the machine is entirely disconnected

from the external circuit. This is not always necessary, but is safest. See that the field resistance is all in circuit. (2) Start the armature turning. (3) When the armature is up to speed, cut out field resistance until the voltage of the machine is normal or equal to that on the bus-bars. (4) Close the line switch, watching the ammeter and voltmeter and make further adjustment with the field rheostat if necessary.

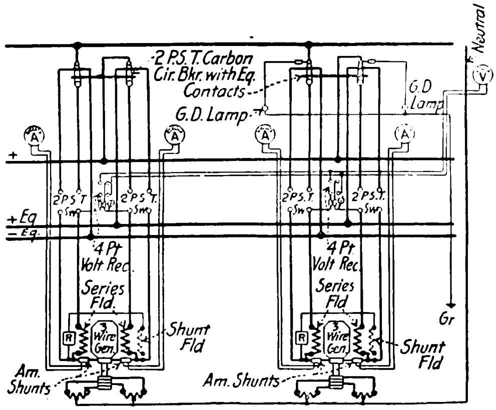


FIG. 14.—Diagram of connections of two three-wire direct-current generators operating in parallel, 125–250 volts.

19. Approximate Data on Standard, Compound-wound, Direct-current, Commutating-pole Generators

The efficiency of a generator depends on its design, and, to a certain extent, on its speed and voltage. Average values are given in the following table that are fairly representative of modern practice.

Kilowatts capacity	Output current, amperes			Efficiency, per cent.		
	125 volts	250 volts	500 volts	½ load	¾ load	Full-load
5	40	20	10	77.0	81.0	82.5
10	80	40	20	82.0	85.0	86.0
15	120	60	30	82.5	86.5	86.5
20	160	80	40	84.0	86.5	87.5
25	200	100	50	85.0	88.0	89.0
35	280	140	70	87.0	89.0	89.5
50	400	200	835	88.0	89.5	90.5
60	480	240	120	88.5	90.5	91.0
75	600	300	150	88.5	90.5	91.0
90	720	360	180	88.5	90.5	91.0
100	800	400	200	89.0	90.5	91.0
125	1,000	500	250	90.5	91.0	91.0
150	1,200	600	300	90.5	91.3	91.5
200	1,600	800	400	91.0	91.5	92.0
300	2,400	1,200	600	91.3	91.8	92.0
400	3,200	1,600	800	91.8	92.3	92.5
500	4,000	2,000	1,000	91.8	92.2	92.5
750	6,000	3,000	1,500	92.0	92.3	92.5
1,000	8,000	4,000	2,000	92.5	93.0	93.5

20. **Nearly all commercial direct-current generators have more than two poles.** In some of the preceding diagrams only two were shown so that the diagrams would be simple. A two-pole machine is a bipolar machine; one having more than two poles is a multipolar machine. Fig. 15 shows the connections and the direction of the magnetic flux of a four-pole machine. Diagrams for machines having more poles would be similar. In multipolar machines there is usually one set of brushes for each pair of poles, but with series-wound armatures, such as are used for railway

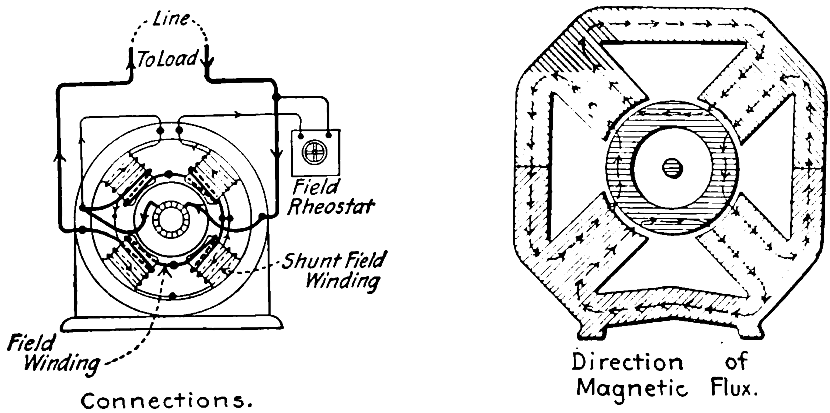


FIG. 15.—Diagrams for four-pole compound-wound generator.

motors, one set of brushes may suffice for a multipolar machine. The connections of different makes of machines vary in detail and the manufacturers will always furnish complete diagrams so no attempt will be made to give them here. The directions of the field windings on generator frames are given in Fig. 16. The directions of the windings on machines having more than four poles are similar in general to those of the four-pole machines.

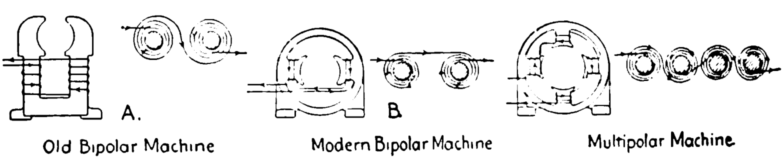


FIG. 16.—Direction of field windings on generator frames.

21. **To Start a Compound-wound Generator.**—(1) See that there is enough oil in the bearings, that the oil rings are working, and that all field resistance is cut in. (2) Start the prime mover slowly and permit it to come up to speed. See that the oil rings are working. (3) When machine is up to normal speed, cut out field resistance until voltage of the machine is normal or equal to or a trifle above that on the bus-bars. (4) Throw on the load. If three separate switches are used, as in Fig. 17, close the equalizer switch first, the series coil line switch second, and the other line switch third. If a three-pole switch is used, as in Fig. 18, all three poles are, of

course, closed at the same time. (5) Watch the voltmeter and ammeter and adjust the field rheostat until the machine takes its share of the load. A machine generating the higher voltage will take more than its share of the load and if its voltage is too high it will run the other as a motor.

22. To Shut Down a Compound-wound Generator Operating in Parallel with Others.—(1) Reduce the load as much as possible by throwing in resistance with the field rheostat. (2) Throw off the load by opening the circuit-breaker, if one is used, otherwise open the main generator switches. (3) Shut down the driving machine. (4) Wipe off all oil and dirt, clean the machine and put it in good order for the next run.

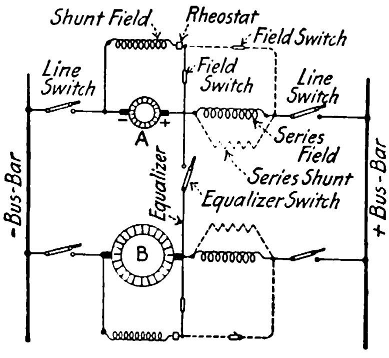


FIG. 17.—Elementary connections for parallel operation of compound-wound generators.

If the machine is operating independently and no motors are connected to the circuit, close the engine throttle valve and permit the engine and generator to come to rest. Turn all resistance in the field rheostat. Open the main switch. Where motors are served they must be disconnected first. If they are not, a loaded

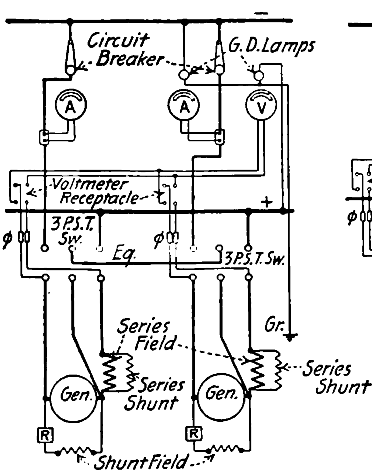


FIG. 18.—Diagram of connections of two compound-wound generators to switchboard (Westinghouse).

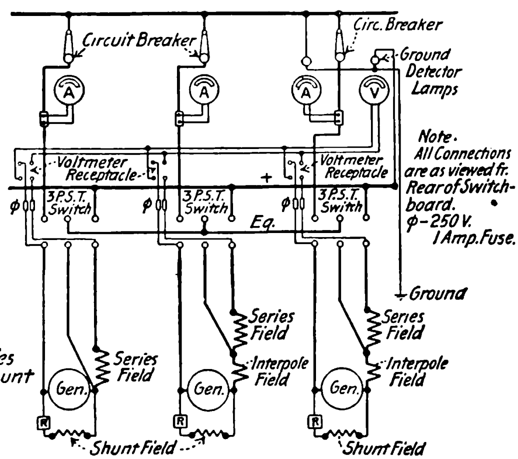


FIG. 18A.—Diagram of connections of two direct-current commutating-pole generators in parallel with one generator without commutating poles.

motor may stop when the impressed voltage decreases somewhat below normal. Then, since its armature is not turning, it is in effect a short-circuit and may blow fuses or make other trouble.

23. To Shut Down a Shunt-wound Generator.—(1) Reduce the load as much as possible by throwing in resistance with the

field rheostat. (2) Throw off the load by opening the circuit-breaker, if one is used, otherwise open the feeder switches and finally the main generator switches. (3) Shut down the driving machine. (4) Wipe off all oil and dirt, clean the machine and put it in good order for the next run.

24. **Parallel Operation of Shunt Generators.**—As suggested in 6 shunt-wound generators do not operate very well in parallel because they do not divide the load well and the voltage of one is apt to rise above that of another and drive it as a motor. When it is running as a motor its direction of rotation will be the same as when it was generating, hence the operator must watch the ammeters closely for an indication of this trouble. Shunt generators are now seldom installed and are seldom operated in parallel, although they will work that way. Where there are several in

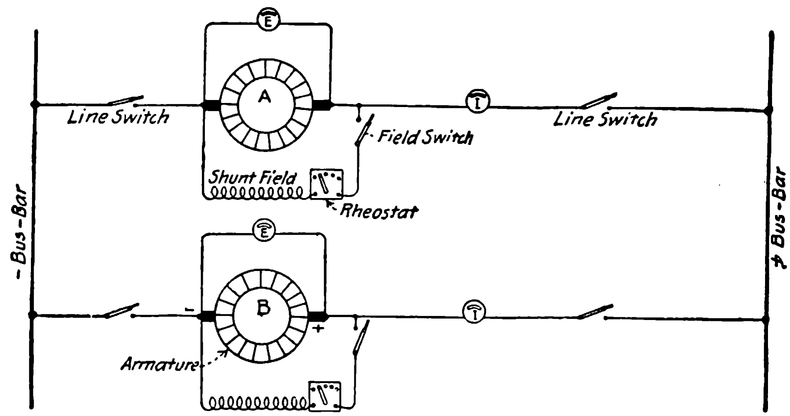


FIG. 19.—Connections for shunt generators for parallel operation.

a plant the best arrangement is to divide the total load between them, giving each its own distinct circuit. Fig. 19 shows the connections for shunt generators that are to be operated in parallel.

25. **Parallel operation of compound-wound generators** is readily effected if the machines are of the same make and voltage or are designed with similar electrical characteristics (*Westinghouse Co.*). The only change usually required is the addition of an equalizer connection between machines. If the generators have different compounding ratios it may be necessary to readjust the series field shunts to obtain uniform conditions.

26. **An equalizer, or equalizer connection,** connects two or more generators operating in parallel at a point where the armature and series field leads join (see Fig. 17), thus connecting the armatures in multiple and the series coils in multiple, in order that the load will divide between the generators in proportion to their capacities. The arrangement of connections to a switchboard (*Westinghouse*) is shown in Fig. 18. Consider, for example, two compound-wound machines operating in parallel without an equalizer. If, for some reason, there is a slight increase in the speed of one machine, it would take more than its share of load. The increased current

flowing through its series field would strengthen the magnetism, raise the voltage, and cause the machine to carry a still greater amount until it carried the entire load. Where equalizers are used, the current flowing through each series coil is proportional to the resistance of the series coil circuit and is independent of the load on any machine; consequently an increase of voltage on one machine builds up the voltage of the other at the same time, so that the first machine cannot take all the load but will continue to share it in proper proportion with the other generators.

27. **Operation of a shunt and a compound dynamo in parallel** is not successful because the compound machine will take more than its share of the load unless the shunt machine field rheostat is adjusted at each change in load.

28. **Three-wire direct-current generators can be operated in multiple** (*Westinghouse Publication*) with each other and in multiple with other machines on the three-wire system (see Figs. 12, 13 and 14). When operating a three-wire, 250-volt generator in multiple with two-wire, 125-volt generators, the series fields of the two two-wire generators must be connected, one in the positive side and one in the negative side of the system, and an equalizer must be run to each machine. Similarly, when operating a three-wire, 250-volt generator in multiple with a 250-volt, two-wire generator, the series field of the 250-volt, two-wire generator must be divided and one-half connected to each outside wire. The method of doing this is to disconnect the connectors between the series field coils and reconnect these coils so that all the N pole fields will be in series on one side of the three-wire system and all the S pole fields in series on the other side of the system.

29. **Switchboard Connections for Three-wire Generators.**—Fig. 12 is a diagrammatical representation of the switchboard connections for two three-wire generators operated in multiple (*Westinghouse Publication*). Two ammeters indicate the unbalanced load. The positive lead and equalizer are controlled by a double-pole circuit-breaker; the negative lead and equalizer likewise. Note that both the positive and negative equalizer connections as well as both the positive and negative leads are run to the circuit-breakers in addition to the main switches on the switchboard. It is necessary that this be done in all cases. Otherwise, when two or more machines are running in multiple and the breaker comes out, opening the main circuit to one of them but not breaking its equalizer leads, its ammeter is left connected to the equalizer busbars and current is fed into it from the other machines through the equalizer leads, either driving it as a motor or destroying the armature winding. (See also Figs. 13 and 14.)

30. **Commutating-pole machines will run in multiple** with each other and with non-commutating-pole machines provided correct connections are made. See illustrations. The series field windings on commutating-pole machines are usually less powerful than on non-commutating-pole; and particular attention should, therefore, be paid to getting the proper drop in accordance with instructions of **32.** A connection diagram is shown in Fig. 18, *A*.

31. **Testing for Polarity.**—When a machine that is to operate

in parallel with others is connected to the bus-bars for the first time it should be tested for polarity. The + lead of the machine should connect to the + bus-bar and the − lead to the − bus-bar (Fig. 20, *I*). The machine to be tested should be brought up to normal voltage, but not connected to the bars. The test can be made with two lamps (Fig. 20, *II*), each lamp of the voltage of the circuit. Each is temporarily connected between a machine terminal and bus terminal of the main switch. If the lamps do not burn, the polarity of the new machine is correct, but if they burn brightly its polarity is incorrect and should be reversed. A voltmeter can be used (Fig. 20, *III*). A temporary connection is

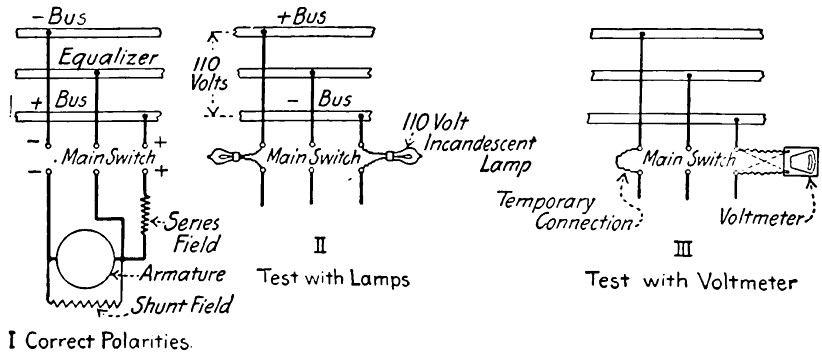


FIG. 20.—Tests for polarity.

made across one pair of outside terminals and the voltmeter is connected across the other pair. No or a small deflection indicates correct polarity. (Test with voltmeter leads one way and then reverse them, as indicated by the dotted lines.) A full-scale deflection indicates incorrect polarity. Use a voltmeter having a voltage range equal to twice the voltage on the bus-bars.

32. **To adjust the division of load between two compound-wound generators:** First adjust the series shunts of both machines so that, as nearly as possible, the voltages of both will be the same at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full-load. Then connect the machines in parallel, as suggested in Fig. 17, for trial. If upon loading, one machine takes more than its share of the load (amperes), increase the resistance of the path through its series-field coil path until the load divides between the machines proportionally to their capacities. Only a small increase in resistance is usually needed. The increase may be provided by inserting a longer conductor between the generator and the bus-bar, or iron or German-silver washers can be inserted under a connection lug. Inasmuch as (when machines are connected in parallel) adjustment of the series coil shunt affects both machines similarly, nothing can be accomplished through making such adjustment.

33. **A series shunt for a compound generator** consists of a low-resistance connection across the terminals of the series field (see Figs. 17 and 18) by means of which the compounding effect

of the series winding may be regulated by shunting more or less of the armature current past the series coils. It may be in the form of grids, on large machines, or of ribbon resistors. In the latter case it is usually insulated and folded into small compass.

34. Connecting Leads for Compound Generators.—See that all the cables that lead from the various machines to the bus-bars are of equal resistance. This means that if the machines are at different distances from the switchboard, different sizes of wire should be used, or resistance inserted in the low-resistance leads. See **32.**

With generators of small capacity the equalizer is usually carried to the switchboard, as suggested in Fig. 18A, but with larger ones it is carried under the floor directly between the machines (Fig. 21). In some installations the positive and the equalizer switch of each machine are mounted side by side on a pedestal near the generator (Fig. 21). The difference in potential between the two switches is only that due to the small drop in the series coil. The positive bus-bar is carried along under the floor near the machines. This permits of leads of minimum length. Leads of equal lengths should be used for generators of equal capacities. If the capacities are unequal (see **32**) it may be necessary to loop the leads. (See Fig. 21.)

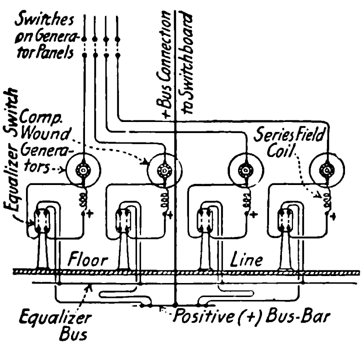


FIG. 21.—Equalizer carried directly between machines.

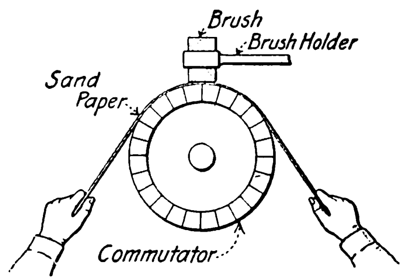


FIG. 22.—Sandpapering brushes.

35. Ammeters for compound generators should, as in Fig. 18, always be inserted in the lead not containing the compound winding. If cut in the compound winding lead the current indications will be inaccurate because current from this side of the machine can flow either through the equalizer or the compound-winding lead.

36. Brushes, their Adjustment and Care (*Westinghouse Instruction Book*).—The position of the brushes on a direct-current machine should be on or near the no-load neutral point of the commutator. This neutral point on most standard, non-commutating pole machines is in line with the center of the pole and the brushes should be set a little in advance of this neutral point. The brushes of non-commutating pole generators should be given a slight "forward lead" in the direction of rotation of the armature. Motor brushes should be set somewhat back of the neutral point, the "backward lead" in this case being approximately equal to

the forward lead on generators. The exact position in either case is that which gives the best commutation at normal voltage for all loads. In no case should the brushes be set far enough from the neutral point to cause dangerous sparking at no-load.

The ends of all brushes should be fitted to the commutator so that they make good contact over their entire bearing faces. This can be most easily accomplished after the brush holders have been adjusted and the brushes inserted as follows: Lift a set of brushes sufficiently to permit a sheet of sandpaper to be inserted. Draw the sand-paper in one direction only, preferably in the direction of rotation, under the brushes (Fig. 22) being careful to keep the ends of the paper as close to the commutator surface as possible and thus avoid rounding the edges of the brushes, each set of brushes being similarly treated in turn. Start with coarse sand paper and finish with fine sand paper. If the brushes are copper plated, their edges should be slightly beveled, so that the copper does not contact with the commutator.

37. Current Taken by Direct-current Motors

Horse-power	Total amperes		
	110 volts	220 volts	500 volts
1	9	4.5	2.0
2	17	8.5	3.7
3	26	13	5.6
5	40	20	8.8
7.5	60	30	13
10.	76	38	17
15	112	56	25
20	150	75	33
25	188	94	41
30	226	113	50
40	302	151	66
50	368	184	81
75	552	276	122
100	736	368	162
150	1,110	555	244
200	1,474	737	324

38. Commutating-pole Generators and Motors, Fig. 23 (*Standard Handbook*).—The principal advantage of the commutating pole construction resides in the fact that with it the commutation can be rendered practically perfect under any condition of service.

39. The object in using the commutating-pole is to produce within the armature coil under commutation an e.m.f. of the proper value and sign to reverse the current in the coil while it is yet under the brush—a result that is essential to perfect commutation. The variation in the flux distribution in the air-gap of a commercial direct-current machine of the ordinary shunt-wound type, at no-load and under full-load, is shown in Fig. 24. Consider now the value and position of the flux in the coil under the brush when the machine is operating at full-load. The motion of the armature through this flux causes the generation within the coil of an e.m.f., and the sign of this e.m.f. is such as to tend to cause the current in the coil to continue in the direction which it had before the coil

reached the brush, and hence it opposes the desired reversal of the current before the coil leaves the brush.

There is an additional detrimental influence which tends to retard the rapid reversal of the current even when all other influences are absent. This latter influence is due to the local magnetizing effect of the current in the coil under the brush. On account of this there

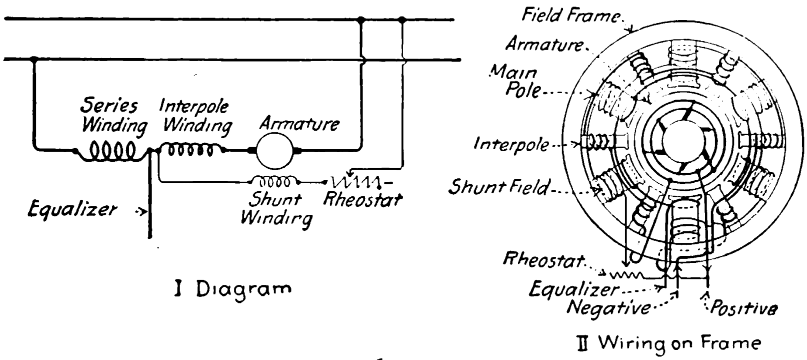


Fig. 23.—Diagram of compound-wound commutating-pole machines.

surround the conductor lines of force, the change in the value of which, with the fluctuations of the current as it tends to be reversed, generates in the coil an e.m.f. which opposes the change in the value of the current. This reactive e.m.f. is in the same direction as that due to the cutting of the flux by the coil under the brush and is likewise proportional to the speed.

It will be apparent that even were the field distortion completely neutralized, the detrimental reactive e.m.f. would yet remain.

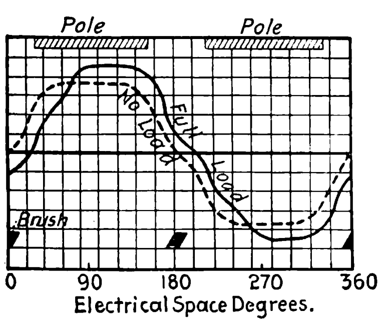


Fig. 24.—Distribution of magnetic flux at no load and at full load, without commutating poles.

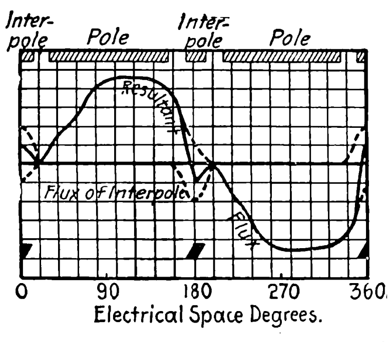


Fig. 25.—Distribution of magnetic flux at full load, with and without commutating poles.

The improved and practically perfect commutation of the commutating-pole motor is due to the fact that the flux, which is locally superposed upon the main field, not only counterbalances the undesirable main flux cut by the coil under the brush, but it causes to be generated within the coil an e.m.f. sufficient to equal and oppose the reactive e.m.f. just referred to. This effect will be

appreciated from a study of Fig. 25, which represents the distorted flux of the motor of the usual design, as shown in Fig. 24, and indicates the results to be expected when the flux due to the auxiliary or commutating pole is given the relatively proper value.

It is worthy of note that this desirable effect is the more pronounced the weaker the main field; and that the commutation voltage, if correct for a low speed, is correct for a high speed; and that with increase of load-current and main-field distortion there is a proportional increase of counter-magnetizing field produced in the coil under the brush, up to the point of magnetic saturation of the auxiliary pole; and that sparkless operation is insured for all operating ranges both of speed and load.

40. **Commutating-pole, direct-current generators** are similar in construction and operation to commutating-pole motors. Ordinary generators (*Westinghouse Co.*) that operate under severe overloads and over a wide speed range are liable to spark under the brushes at the extreme overloads and at the higher speeds. This is because the field due to the armature current distorts the main field to such an extent that the coils being commutated under the brush are no longer in a magnetic field of the proper direction and strength. To overcome this, interpoles are placed between the main poles. (See Fig. 23.) These interpoles introduce a magnetic field of such direction and strength as to maintain the magnetic field, at the point where the coils are commutated, at the proper strength for perfect commutation. Commutating-poles are sometimes called interpoles but probably "*commutating-pole*" is the preferable term.

The winding in the interpoles is connected in series with the armature so that the strength of the corrective field is proportional to the load. The adjustment and operation of interpole generators is not materially different from that of non-interpole machines.

When the brush position of an interpole machine has once been properly fixed, no shifting is afterward required or should be made, and most interpole generators are shipped without any shifting device. An arrangement for securely clamping the brush-holder rings to the field frame is provided.

In interpole apparatus accurate adjustment of the brush position is necessary. The correct brush position is on the no-load neutral point, which is located by the manufacturer. A templet is furnished with each machine or some other provision is made whereby the brush location can be determined in the field. If the brushes are given a backward lead on an interpole generator, the machine will over-compound and will not commutate properly. With a forward lead of the brushes, a generator will under-compound and will not commutate properly.

41. **The action of the magnetic flux in a commutating-pole generator** is illustrated in Fig. 26. The direction of the main field flux is shown by the dashed line. The direction of the armature magnetization is shown by the dotted lines. The direction of the flux in the interpole is shown by the full line. It is evident that the interpole flux is in a direction opposite to that of the armature flux, and as the interpole coil is more powerful in its magnetizing

action than the armature coils, the flux of the armature coils is neutralized. With a less powerful magnetizing force from the interpole than from the armature, the armature would overpower the interpole and reverse the direction of the flux, which would result in a very bad commutating condition.

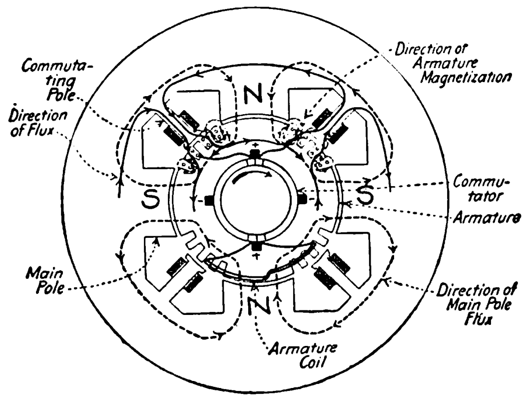


FIG. 26.—Distribution of flux in a commutating-pole generator.

42. **Commutating-pole, Three-wire Generators.**—On three-wire generators connections are so made that one-half of the interpole winding is in the positive side and the other half is in the negative side. This insures proper action of the interpoles at unbalanced load. (See Figs. 12, 13 and 14 and the text accompanying them.)

43. **To reverse the direction of rotation of a commutating-pole generator,** reverse the shunt and series fields as in an ordinary generator.

TROUBLES OF DIRECT-CURRENT MOTORS AND GENERATORS—THEIR LOCALIZATION AND CORRECTION

Table No. 44.—Pages 174 to 184 inclusive—troubles of direct-current motors and generators.

44. Direct-current Generator and Motor Defects

(From *Machinery* by special permission)

Sparking at the brushes.	Faults of	Brushes.	Not set diametrically opposite.	*A*. Should have been set properly at first, by counting bars, or by measurement on the commutator. *B*. Can be done if necessary while running; move rocker until brush on one side sparks least, then adjust other brushes so they do not spark.	1
			Not set at neutral points.	Move rocker back and forth slowly until sparking stops.	2
			Not properly trimmed.	*A*. Brushes should be properly trimmed before starting. If there are two or more brushes one may be removed and retrimmed. *B*. Clean with alcohol or ether, then grind and reset carefully. *See* lines 1, 4, 38.	3
			Not in line.	Adjust each brush until bearing is on line and square on commutator bar, bearing evenly the whole width. *See* line 13 *A*.	4
			Not in good contact.	*A*. Clean commutator of oil and grit. See that brushes touch. *B*. Adjust tension screws and springs to secure light, firm and even contact. *See* line 38 *C*.	5
		Commutator.	Rough; worn in grooves or ridges; out of round.	*A*. Grind with fine sandpaper on curved block, and polish with crocus cloth. Never use emery in any form.	6
				B. If too bad to grind down turn off true in a lathe or preferably in its own bearings, with a light tool and rest, a light cut; running slowly. *Note*.—Armature should have $\frac{1}{16}$ to $\frac{1}{8}$ in. end motion when running, to wear commutator evenly and smoothly. *See* line 31.	7
			High bars.	Set "high bar" down carefully with mallet or block of wood, then clamp tightly end nuts, or file, grind or turn true. A high bar may cause singing. *See* line 38.	8
			Low bars.	Grind or turn commutator true to the surface of the low bars.	9
			Weak magnetic field.	*A*. Broken circuit } in field coils { Repair if external. *B*. Short circuit } in field coils { Rewind if internal. *C*. Machine not properly wound, or without proper amount of iron—no remedy but to rebuild it.	10

Direct-current Generator and Motor Defects (*Continued*)

Sparking at the brushes.	Excessive current in armature. - - -	Generator.	Excessive load.	*A.* Reduce number of lamps and load.	11
			Ground and leak from short-circuit on line.	*B.* Test out, locate, and repair.	
			Dead-short circuit on line.	*C.* *Note.*—Dead short-circuit will or should blow safety fuse. Shut down, locate fault and repair before starting again, and put in a new fuse.	
		Motor.	Excessive voltage.	*D.* Use proper current only, and with proper rheostat and controller and switch.	
			Excessive amperes on constant-current circuit.	*E.* See that controller, etc., are suitable with ample resistance.	
			Friction.	*F.* Reduce load on motor to its rated capacity or less. *See* 3 *B* and 35, 36.	
			Too great load on pulley.	*G.* See that there is no undue friction or mechanical resistance anywhere.	
	Armature faults.	Short-circuited coils.		*A.* Remove copper dust, solder or other metallic contact between commutator bars. *B.* See that clamping rings are perfectly free, and insulated from commutator bars; no copper dust, carbonized oil, etc., to cause an electrical leak. *C.* Test for cross connection or short-circuit, and if such is found rewind armature to correct. *D.* See that brush holders are perfectly insulated. No copper dust, carbon dust, oil or dust, to cause an electrical leak. *See* lines 1, 2, 60.	12
		Broken coils.		*A.* Bridge the break temporarily by staggering the brushes, until machine can be shut down (to save bad sparking) and then repair. *B.* Shut down machine if possible, and repair loose or broken connection to commutator bar. *C.* If coil is broken inside, rewinding is the only sure remedy. May be temporarily repaired by connecting to next coil, across mica. *D.* Solder commutator lugs together, or put in a "jumper," and cut out, and leave open the broken coil. Be careful not to short-circuit a good coil in doing this. *See* line 12.	13
		Cross connections.		Cross connections may have same effect as short-circuit, treat as such, *see* line 12. Each coil should test complete without cross and no ground.	14

Direct-current Generator and Motor Defects (*Continued*)

Heating of parts.	Armature.	Overloaded.		Overload. Too many amperes, lights, or too much power being taken from machine. *See* 11, 12, 13, 14.	15
		Short-circuit.		Short-circuited. Generally dirt, etc., at commutator bars. *See* 11, 12, 13, 14.	16
		Broken circuit.		Broken circuit. Often caused by a loose or broken band. *See* 11, 12, 13, 14.	17
		Cross connection.		Cross connection. Often caused by a loose coil abrading on another coil or core. *See* 11, 12, 13, 14.	18
		Moisture in coils.		Dry out by gentle heat. May be done by sending a small current through, or causing machine to generate a small current itself, by running slowly.	19
		Eddy currents in core.		Iron of armature hotter than coils after a run. Faulty construction. Core should be made of finely laminated insulated sheets. No remedy but to rebuild.	20
		Friction.		Hot boxes or journals may affect armature. *See* 23, 33 below.	21
	Field coils.	Excessive current.	Shunt.	*A.* Decrease voltage at terminals by reducing speed. Increase field resistance by winding on more wire, finer wire, or putting resistance in series with fields.	22
			Series.	*B.* Decrease current through fields by shunt, removing some of field winding or rewind with coarser wire.	
				Note.—Excessive current may be from a short circuit, or from moisture in coils, causing a leakage. *See* 10, 24.	
		Eddy currents.		Pole pieces hotter than coils after short run, due to faulty construction, or fluctuating current, if latter, regulate, and steady current.	23
		Moisture in coils.		Coils show less than normal resistance, may cause short circuit or body contact to iron of dynamo. Dry out as in 19. *See also* 22 *note.*	24
	Bearings.	Not sufficient or poor oil.		*A.* See that plenty of good mineral oil, filtered clean, and free from grit, feeds; but be careful that it does not get on commutator or brush holder. *See* 12. *B.* Cylinder oil or vaseline may be used if necessary to complete run, mixed with sulphur or white lead, or hydrate of potash. Then clean up and put in good order.	25

Direct-current Generator and Motor Defects (*Continued*)

Heating of parts.	Bearings.	Dirt or grit in bearings.	*A*. Wash out grit with oil while running, then clean up and put in order. Be careful about flooding commutator and brush holder. *B*. Remove caps and clean and polish journals and bearings perfectly, then replace. See that all parts are free and lubricate well. *C*. When shut down, if hot, then remove bearings and let them cool naturally, then clean, scrape and polish, assemble; see that all parts are free and lubricate well.	26
		Rough journals or bearings.	Smooth and polish in a lathe, removing all burrs, scratches, tool marks, etc., and rebabbitt old boxes and fit new ones.	27
		Journals too tight in bearings; bent shaft.	Slacken cap bolts, put in liners and retighten till run is over, then scrape, ream, etc., as may be needed, bend or turn true in lathe or grinder. Possibly a new box or shaft will be needed.	28 29
		Bearings out of line.	Loosen bearing bolts, line up and block, until armature is in center of pole pieces, ream out dowel and bolt holes and secure in new position.	30
		End pressure of pulley hub or shaft collars.	*A*. See that foundation is level and armature has free end motion. *B*. If there is no end motion, file or turn ends of boxes or shoulders on shaft to provide end motion. *C*. Then line up shaft and belt, so that there is no end thrust on shaft, but that the armature plays freely endways when running.	31
		Belt too tight.	*A*. Reduce load so that belt may be loosened and yet not slip. Avoid vertical belts if possible. *B*. Choose larger pulleys, wider and longer belts with slack side on top. Vibrating and flapping belts cause winking lamps.	32
		Armature out of center of pole pieces.	*A*. Bearings may be worn out and need replacing, throwing armature out of center. *See* 36. *B*. Center armature in polar space, and adjust bearings to suit. *See* 30. *C*. File out polar space to give equal space all round. *D*. Spring pole away from armature; this may be difficult or impossible in large machines.	33

Direct-current Generator and Motor Defects (*Continued*)

Noises.		Armature or pulley out of balance.	Faulty construction, armature and pulley should have been balanced when made. May be helped by balancing on knife edges now.	34
		Armature strikes or rubs pole pieces.	*A*. Bend or press down any projecting wires, and secure with tie bands. *B*. File out pole pieces where armature strikes. *See* 30, 33.	35
		Collars or shoulders on shaft strike or rub box.	Bearings may be loose or worn out. Perhaps new bearings are needed. *See* 30, 31.	36
		Loose bolt connection or screws.	See that all bolts and screws are tight, and examine daily to keep them so.	37
		Brushes sing or hiss.	*A*. Apply stearic acid (adamantine) candle, vaseline, or cylinder oil to commutator and wipe off; only a trace should be applied. *B*. Move brushes in and out of holder to get a firm, smooth, gentle pressure, free from hum or buzz. *See* 3, 6, 7, 8, 9, 31.	38
		Flapping of belt.	Use an endless belt if possible, if a laced belt must be used, have square ends neatly laced.	39
		Slipping of belt from overload.	Tighten belt or reduce load. *See* 32.	40
		Humming of armature lugs or teeth.	*A*. Slope end of pole piece so that armature does not pass edges all at once. *B*. Decrease magnetism of field, or increase magnetic capacity of tooth.	41
Speed.	Runs too fast.	Engine fails to regulate with varying load.	Adjust governor of engine to regulate properly, from no-load to full-load, or get a better engine.	42
		Series motor, too much current, and runs away.	*A*. Series motor on constant current—(1) Put in a shunt and regulate to proper current; (2) use regulator or governor to control magnetism of field for varying load. *B*. Series motor on constant potential—(1) Insert resistance and reduce current; (2) use a proper regulator or controlling switch; (3) change to automatic speed-regulating motor.	43

Direct-current Generator and Motor Defects (*Continued*)

Speed.	Runs too fast.	Shunt motor.	Field rheostat not properly set.	*A.* Adjust field rheostat to control motor.	44
			Not proper current.	*B.* Use current of proper voltage and no other, with a proper rheostat.	
			Motor not properly proportioned.	*C.* Get a better motor, one properly designed for the work.	
	Runs too slow.	*See note below table.*		45, same as 42; 46, *see* 11 *A*; 47, short circuit in armature, *see* 12; 48 rubbing armature, *see* 35; 49, friction, *see* 3 *B*; 50, weak magnetic field, *see* 10.	
Motor.	Stop or fail to start.		Great overload. *See* 11 *F* and *G*.	Open switch, find and repair trouble. Keep switch open and rheostat "off" to see if everything is right.	51
			Excessive friction. *See* 25, 33, 35.	Shunt motor on constant potential circuit, fuse may blow or armature burn out.	52
		Circuit open.	Fuse melted or switch open.	*A.* Find and repair trouble after opening switch, then put in fuse. *See* 11 *C*.	53
			Broken wire or connection.	*B.* Open switch, find and repair trouble. *See* 13.	
			Brushes not in contact.	*C.* Open switch and adjust. *See* 5.	
			Current fails or is shut off at station.	*D.* Open switch and return starting box lever to off position, wait for current.	
			Short-circuit of field.	Test for and repair if possible. Examine insulation of binding posts and brush holders.	54
			Short-circuit of armature. Short-circuit of switch.	Poor insulation, dirt, oil, and copper, or carbon dust often result in a short-circuit.	56
	Runs backward. Wrong connections.			Connect up correctly per diagram; if no diagram is at hand, reverse connections to brushes or others until direction of rotation is satisfactory.	57

Note from line 50.—45, Engine fails to regulate. 46, Overload. 47, Short-circuit in armature. 48, Striking or rubbing of armature. 49, Friction. 50, Weak magnetic field.

Direct-current Generator and Motor Defects (*Continued*)

Dynamo or generator.	Reversed residual magnetism.	Reversed current through field coils. Reversed connections. Earth's magnetism. Proximity of another dynamo. Brushes not in right position. *See* 1, 2, 3.	*A*. Use current from another machine or a battery through field in proper direction to correct fault. Test polarity with a compass. *B*. If connections or winding are not known, try one way and test; if not correct reverse connections, try again and test. *C*. Connect up per diagram for desired rotation, see that connections to shunt and series coils are properly made. *See* 57. *D*. Shift brushes until they operate better. *See* 1, 2, 3.	58
		Too weak residual magnetism.	Same as 58 *A*.	59
		Short-circuit in machine.	*See* 12, 54, 56.	60
		Short-circuit in external circuit.	A lamp socket, etc., may be short-circuited or grounded, and prevent building up shunt or compound machines. Find and remedy before closing switch. *See* 54, 56.	61
		Field coils opposed to each other.	Reverse connections of one of field coils and test. Find polarity with compass; if necessary try 58 *A*, *C*, *D*. If necessary reverse connections and recharge in opposite directions.	62
	Open circuit.	Broken wire. Faulty connections. Brushes not in contact. Safety fuses melted or broken. Switch open. External circuit open.	*A*. Search out and repair. *See* 13. *B*. Search out and repair. *See* 37. *C*. Search out and repair. *See* 5. *D*. Search out and repair. *See* 53 *A*. *E*. Search out and repair. *See* 53 *D*. *F*. Search out and repair with dynamo switch open until repairs are completed.	63
		Too great load on dynamo.	Reduce load to pilot lamp on shunt and incandescent machines; after voltage is obtained close switches in succession slowly, and regulate voltage. *See* 11 *A* and 65.	64
		Too great resistance in field rheostat.	Bring up to voltage gradually with rheostat, and watch pilot lamp; regulate carefully.	65

45. Troubles of Direct-current Motors.—Much of the material under this heading is based on that in the book *Motor Troubles* by E. B. Raymond. For more-complete information relating to direct-current-motor-and-generator troubles, see the author's ELECTRICAL MACHINERY, published by the McGraw-Hill Book Company.

46. Measurement of the insulation resistance of generators will give an indication of the average condition of the insulation as regards moisture and dirt, but will not always detect weak spots (*Westinghouse Co.*). The higher the resistance, the better the general condition of the insulating material. The approximate figure of one megohm per thousand volts of rated e.m.f. when the machine is at its normal full-load temperature may be taken as indicating a fairly satisfactory condition of the armature insulation. The insulation resistance of the field will be much higher in proportion to the e.m.f. of the exciting current and will seldom give appreciable trouble. Since large armatures have much greater areas of insulation, their insulation resistance will be proportionally lower than that of small machines. Even though the material is in exactly the same condition, the insulation resistance of any machine will be much lower when hot than when cool, especially when the machine is rapidly heated.

The only feasible method of increasing the insulation resistance after the machine has been completed by its manufacturer is by "drying out." Armature winding and field coils are dried by heat;

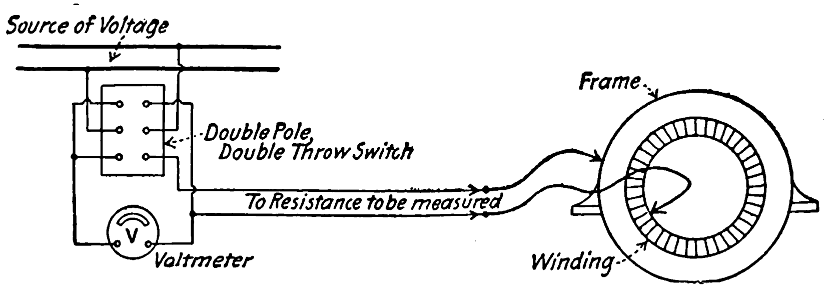


FIG. 27.—Measuring generator insulation resistance.

baking in an oven is to be preferred, but is often impracticable. They are usually heated by the passage of current. For an armature this may be done by short-circuiting the leads and running the generator with a low field charge, just sufficient to produce the proper current. (See 47.)

Insulation resistance may be conveniently measured with a high-resistance voltmeter specially designed for the purpose as directed in the first section (see Index). Voltmeters having a resistance of one megohm are now made for this purpose so that, if one of these instruments is used, the calculation is somewhat simplified. A double-pole switch arranged as indicated in Fig. 27 is convenient for changing the voltmeter connections. If a grounded circuit is used in making this measurement, care must be taken to connect the grounded side of the line to the frame of

the machine to be measured, and the voltmeter between the windings and the other side of the circuit.

47. **Drying Out a Generator or Motor.**—If a generator has been exposed to dampness, before being started in regular service it should be operated with its armature short-circuited beyond the ammeters and with the field current adjusted so as to raise temperature to about 70 deg. cent. The current should then be lowered and raised by means of the field adjustment until the coils become thoroughly dry. The temperature should not be allowed to drop to that of the surrounding atmosphere, as the moisture would then again be condensed on the coils, and the machine brought to the same condition as at the start.

There is always danger of overheating the windings of a machine when drying them with current, as the inner parts, which cannot quickly dissipate the heat generated in them and which cannot be examined, may get dangerously hot, while the more exposed and more easily cooled portions are still at a comparatively moderate temperature. The temperature of the hottest part accessible should always be observed while the machine is being dried out in this way, and should not be allowed to exceed the boiling-point of water. It may require several hours or even days to thoroughly dry out a machine, especially if it is of large capacity. Large field coils dry very slowly. Insulation is more easily injured by overheating when damp than when dry.

48. **When starting up, a generator may fail to excite itself** (*Westinghouse Instruction Book*). This may occur even when the generator operated perfectly during the preceding run. It will generally be found that this trouble is caused by a loose connection or break in the field circuit, by poor contact at the brushes due to a dirty commutator or perhaps to a fault in the starting box or rheostat, or incorrect position of brushes. Examine all connections; try a temporarily increased pressure on the brushes; look for a broken or burnt out resistance coil in the rheostat. An open circuit in the field winding may sometimes be traced with the aid of a magneto bell; but this is not an infallible test as some magnetos will not ring through a circuit of such high resistance and reactance even though it be intact. If no open circuit is found in the starting box or in the field winding, the trouble is probably in the armature. But if it be found that nothing is wrong with the connections or the winding it may be necessary to excite the field from another generator or some other outside source.

Calling the generator we desire to excite No. 1, and the other machine from which current is to be taken No. 2, the following procedure should be followed. Open all switches and remove all brushes from generator No. 1; connect the positive brush holder of generator No. 1 with the positive brush holder of generator No. 2; also connect the negative holders of the machines together (it is desirable to complete the circuit through a switch having a fuse of about 5 amp. capacity in series). Close the switch. Where the generator in trouble connects to bus-bars fed by other generators, the same result can be effected by insulating the brushes of the machine in trouble from their commutator and closing the main

switch. (See Fig. 28.) If the shunt winding of generator No. 1 is all right, its field will show considerable magnetism. If possible, reduce the voltage of generator No. 2 before opening the exciting circuit; then break the connections. If this cannot be done, throw in all the rheostat resistance of generator No. 1; then open the switch very slowly, lengthening out the arc which will be formed until it breaks.

A simple means for getting a compound-wound machine to pick up is to short-circuit it through a fuse having approximately the current capacity of the generator. (See Fig. 29.) If sufficient current to melt this fuse is not generated, it is evident that there is something wrong with the armature, either a short-circuit or an open circuit. If, however, the fuse has blown, make one more

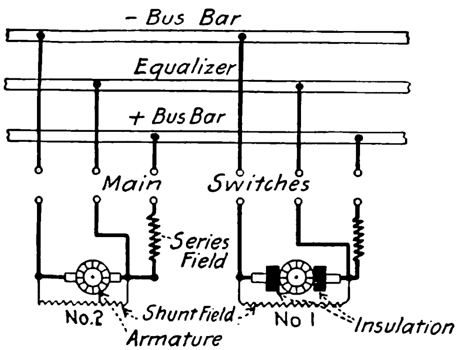


FIG. 28.—Exciting a generator.

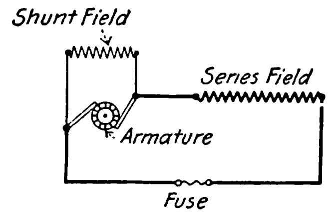


FIG. 29.—Another method of exciting a generator.

attempt to get the machine to excite itself. If it does not pick up, it is evident that something is wrong with the shunt winding or connections.

If a new machine refuses to excite and the connections seem to be all right, reverse the connections, *i.e.*, connect the wire which leads from the positive brush to the negative brush and the wire which leads from the negative brush to the positive brush. If this change of connections does no good, change back and locate the fault as previously suggested.

49. The proper connections for a shunt motor are as shown in Fig. 30. The field *B* is connected as shown, so that when the switch *D* is closed it becomes excited before the armature circuit through the switch *E* is closed. Thus when the motor armature has current admitted to it through switch *E* and starting resistance-box *A*, the field is already on, and the full torque of the motor is obtained. The torque of a motor is equal to the product of flux per pole, the ampere turns on the armature, and the number of poles. Hence, if the full field is not on the motor at starting, full torque will not be obtained.

50. If a motor will not start when the starting-box is operated and when current is flowing in the armature, an investigation should be made to see if the field flux is on, which can be done by

holding a piece of iron, such as a key, against the pole-piece. If the flux exists the key will be drawn strongly against the pole-piece; if there is no flux there will be practically no attraction.

51. **Reversed Field-spool Connection.**—There may be cases where the manufacturer has shipped a motor with one or more field spools reversed. If such is the case no torque, or, perhaps, very weak torque, will be noticed. Under such conditions a trial

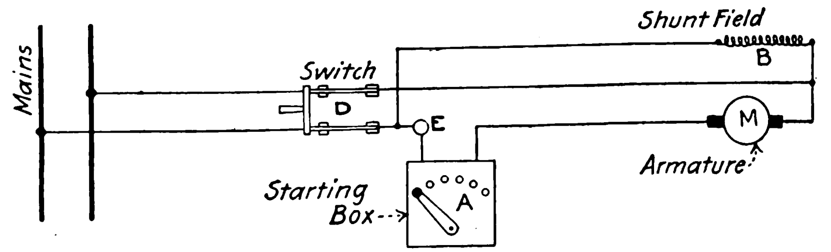


FIG. 30.—Control apparatus connections for a shunt motor.

with an iron key will show proper field magnetism, yet the weakness or total absence of torque will be present, and a trial of polarity should be made.

52. **Running in the Wrong Direction.**—Sometimes a motor when set up and started will run in the wrong direction. The only change necessary is to reverse the field connection. Thus Fig. 31, *I*, shows the connection for one direction of rotation and

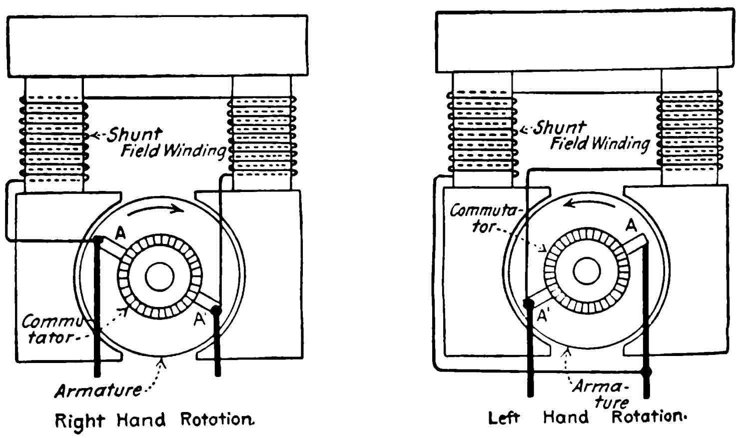


FIG. 31.—Connections for shunt-wound motors.

Fig. 31, *II*, that for the other. Note that in Fig. 31, *I*, the brushes *A* and A^1 are shifted backward against the direction of rotation. For the opposite rotation, a backward lead, as shown in Fig. 31, *II*, must be chosen.

53. **Testing Polarity of Field.**—This can be done in two ways: First, by using a compass, bringing it near the various poles and noting the direction of the deflection of the needle. Since in all motors the poles alternate in magnetic polarity, in one pole the

magnetism coming out and the next going in, it follows that a certain end of a compass needle will point toward one pole and away from the next when conditions are normal. If, however, two adjacent poles show similar magnetism, the trouble is located, and the offending spool should be reversed. This should be done "end for end," not by turning on the axis. The latter operation does not change the direction of magnetism, while the former does. Direction of magnetism is determined by the following rule:

"Looking at the face of an electromagnet (such as the field spool of a motor), a pole will be north if the current is flowing around it in a direction opposite to the motion of the hands of a watch," Fig. 32, and south if in the same direction as the motion of the hands of a watch. (See also the rules outlined in Sect. I of this book.)

Another method of determining whether the magnetism of the poles is correct is to use two ordinary nails, their lengths depending upon the distance between pole-tips. The point of one nail should touch one pole-tip, the point of the other nail the other pole-tip, and the heads of the nails should touch each other.

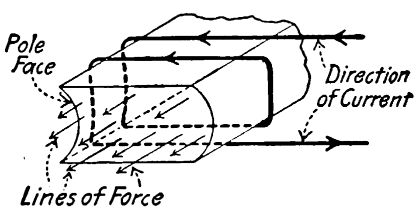


FIG. 32.—Direction of magnetism and current about a pole.

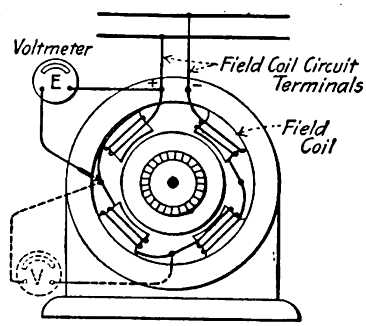


FIG. 33.—Locating field-coil troubles.

When the current flows around the field spools, the polarity between any two poles is properly related if the nails placed as suggested stick together by the magnetism. If there is no tendency to stick, the polarity of the two poles is alike and therefore wrong.

54. **Open Field Circuit.**—If, on closing the field switch, no magnetism is obtained by trial with an iron key, as suggested above, there is an open circuit within one of the spools or in the wires leading to these spools. The open circuit can be located by cutting out one spool at a time and allowing current to flow through the rest until the defective spool is discovered. On a two-pole motor try first one spool and then the other. For a very short time, say, 10 min., double voltage can be carried on a spool. On a motor having four or more poles, three spools can always be left in circuit during the open-circuit investigations.

55. **A method of locating an open-circuited field coil** is illustrated in Fig. 33. Connect one terminal of the voltmeter to one side of the field-coil circuit and with the bared end of a wire or a contactor, successively touch the junctions of the field-coil leads around the frame. When the open coil is bridged the voltmeter will show a full deflection. Another way: Connect the field-coil circuit ter-

minals to a source of voltage. Connect the voltmeter successively across each coil as indicated by the dotted lines in Fig. 33. There will be no deflection on the voltmeter until the open coil is bridged, when the full voltage of the circuit will be indicated.

56. **A grounded field coil can be located** (Fig. 34) by connecting a source of voltage to the machine terminals having first raised the brushes from the commutator, if it is a direct-current machine. Connect one terminal of the voltmeter to the frame and the other to a lead with a bared end. Tap with the bared end exposed parts of the field circuit. The voltmeter deflection will be least near the grounded coil.

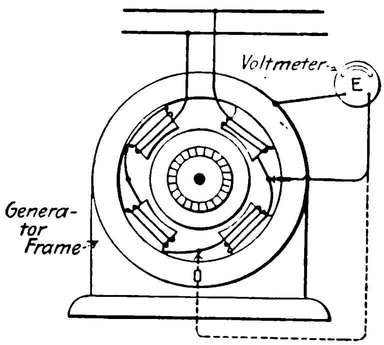


FIG. 34.—Locating grounded coil.

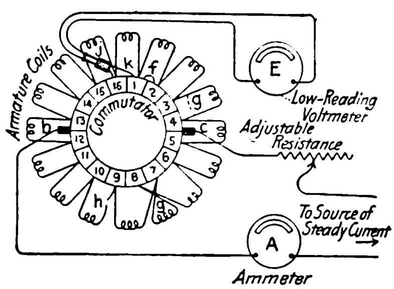


FIG. 35.—Method of testing an armature.

57. **Heating of Field Coils** (*Westinghouse Instruction Book*).—Heating of field coils may develop from any of the following causes: (a) Too low speed; (b) too high voltage; (c) too great forward or backward lead of brushes; (d) partial short-circuit of one coil; (e) overload.

58. **Direct-current armatures can be tested for the common troubles** with the arrangement of Fig. 35. Terminals *b* and *c* are clamped to the commutator at opposite sides and connected with a source of steady current through an adjustable resistance and an ammeter. The terminals of a low-reading voltmeter (a galvanometer can often be used) are connected to two bare metal points, which are separated by an insulating block, *j*. In use, the current is adjusted to produce a convenient deflection of the voltmeter when each of the points rests on an adjacent bar. The points are moved around the commutator and bridged across the insulation between every two bars. If the voltmeter deflection is the same for every pair of bars it indicates that there is no trouble in the armature.

59. **Sparking Due to Open Armature Circuit.**—A cause of a sparking commutator is an open circuit in the winding, either in the armature body or, more often, where the lead from the armature winding is soldered to the commutator. In the latter case resoldering is a ready remedy. If, however, the location of the point of open circuit cannot be found, the bars can be bridged over on the

commutator itself by fastening with solder, or otherwise, a strip of copper around the segments which indicate the break.

The indication of this trouble is very apparent, for, if an open circuit exists, the long heavy spark which accompanies it soon eats away the mica between the two segments which are on each side of the break. This shows positively where to bridge over. An open circuit also shows itself, when the machine is running, by the viciousness of the spark. It is unlike any other kind of commutator sparking, being heavy, long, and destructive in its action.

60. **A poor connection between a bar and coil leads** will cause a considerable deflection of the voltmeter (Fig. 35) when one of the points rests on the bar in trouble and the other rests on either of the adjacent bars.

61. **An open-circuited coil,** as *h*, Fig. 35, will prevent the flow of current through its half of the armature. There will be no deflection on that half of the armature until the "open" is bridged, when the voltage of the testing circuit will be indicated.

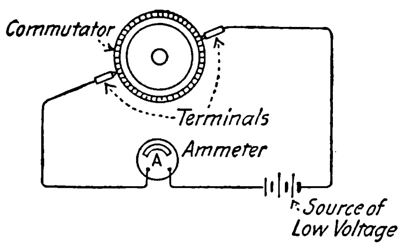


FIG. 36.—Testing for armature open-circuit with an ammeter.

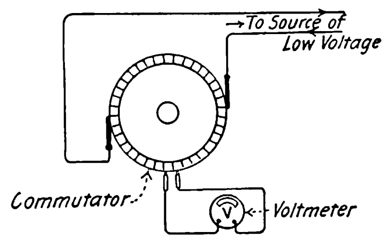


FIG. 37.—Testing for armature open-circuit with a voltmeter.

62. **Tests for Open Armature Circuits.**—Another method (Fig. 36) is to apply to the commutator, at two opposite points, a low voltage, say from a battery or a dynamo with its voltage kept low. Place an ammeter in circuit and clean the surface of the commutator so that it is bright and smooth.

The terminal ends leading the current into and out of the commutator should be small, so that each rests only on a single segment (Fig. 36). Note the ammeter reading and rotate the armature slowly. At the point where the open circuit exists the ammeter needle will go to zero if the leads to the commutator bar have become entirely open-circuited. This is because the segment is attached to the winding through the commutator leads.

If the armature does not show the above symptoms, try connecting a low-reading voltmeter or a galvanometer to two adjacent segments while the current is passing through the armature as described from some external low-voltage source (Fig. 37). Note the deflection. Pass from segment to segment in this manner, recording the drop between the successive pair of bars. This drop, if the current is held constant from the external source, should be the same between each pair of adjacent segments. If any pair shows a higher drop than the others near it, a higher re-

sistance connection exists there, perhaps causing sparking and biting of commutator insulation, to a less degree, to be sure, than with an actual open circuit, but enough, perhaps, to cause the trouble requiring the investigation.

63. **The test for armature short-circuits,** described in the preceding paragraph, is called a "bar to bar" test. It is most valuable in locating faults in armatures. It is the method to use if a short-circuit from one segment to another is suspected. When the section in which the short-circuit, or partial short-circuit, exists comes under the contacts, a low or perhaps no deflection is shown on the galvanometer or voltmeter, thus locating the defective place. Such short-circuits, if they occur when running, owing to defective insulation, burn out the coil short-circuited. When the coil passes through the active field in front of the pole-piece, an immense current is induced in it, causing a destruction of the insulation. When this occurs the coil should be open-circuited if the burning has not already short-circuited it. If practical, it should be bridged over, as suggested in a preceding paragraph.

64. **If two bars or a coil is short-circuited** as at *f* and *g* (Fig. 35) respectively, there will be little or no voltmeter deflection when the two bars connecting to the "short-circuit" are bridged by the points.

65. **A grounded armature coil** can be detected in the same manner as indicated in Fig. 34 for a field coil. Impress full voltage on the terminals clamped to the commutator. Ground one side of the voltmeter on the shaft or spider and touch a lead connected to the other side to all the bars in succession. The minimum deflection will obtain when the bars connecting to the grounded coil are touched.

66. **Crossed coil leads** as at *g* (Fig. 35) are indicated by a twice normal deflection when the points bridge the bars to which the crossed coils should rightly connect. The crossing of the coil leads connects two coils in series, hence causes twice normal drop. Bridging the bars to which coil *h* connects will produce a normal deflection, but it will be reversed in direction.

67. **Reversed Armature Coil.**—Instead of the armature winding progressing uniformly around from bar to bar of the commutator, there may at some point be a coil connected in backward. Such a reversed coil often causes bad sparking. One way to locate such a trouble is to pass through the armature, at opposite points on the commutator, a current. Then with a compass explore around the armature the direction of magnetism from slot to slot. If a coil is reversed when the compass comes before it, the needle will reverse, giving a very definite indication of the improperly connected coil.

68. **Heating of Armature** (*Westinghouse Instruction Book*).—Heating of the armature may develop from any of the following causes: (a) Too great a load; (b) a partial short-circuit of two coils heating the two particular coils affected; (c) short-circuits or grounds on armature or commutator.

69. **Hot Armature Coils.**—Sometimes when a new machine is

started, local heating occurs in the armature, following the exact shape of the armature coil. This may be because, in receiving its final turning off, the commutator bars were bridged with copper from one segment to another by the action of the turning tool. An examination of the commutator surface will reveal this bridging. When it is removed, satisfactory operation will ensue if the trouble has not gone too far and seriously injured the insulation of the coil.

70. Care of Commutators.—They should be kept smooth by the occasional use of No. 00 sandpaper. A small quantity of high grade, light body oil should be used as a lubricant. The lubricant should be applied to high-voltage generators by aid of a piece of cloth attached to the end of a dry stick. If the commutator gets "out of true" it should be turned down. By using a special slide rest and tool this can be done while running the engine at a reduced speed without removing the rotating part from the bearings. Inspect the commutator surface carefully to see that the copper has not been burned over from segment to segment in the mica and remove by a scraper any particles of copper which may be found embedded in the mica. Keep oil away from the mica end-rings of the commutator as oily mica will soon burn out and ground the machine.

71. Process of Commutation and Correction of Glowing and Pitting.—The path of the current is as shown in Fig. 38. A is the carbon brush; C, C', C'' are the commutator segments; B, B', B'' are the windings of the armature. At the position shown, coil B is short-circuited by the carbon, the current passing into the face of the brush and out again as shown by the dotted line. This local current may be many times larger than the normal flow of current and is the one that causes pitting.

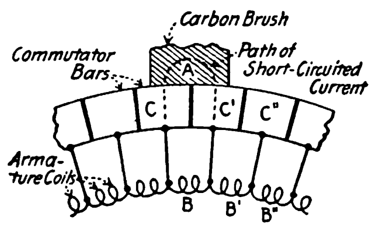


FIG. 38.—Armature coil short-circuited when commutating.

With perfect commutation, with no sparking or glowing, there should be created in the short-circuited coil under the brush, by means of the flux from that pole-tip away from which the armature is revolving, an electromotive force. This should be just large enough to reverse the current within the short-circuited coil and to render it equal to the current in the winding proper. Since on one side of the brush the current is in one direction and on the other side in the other direction, the act of commutation beneath the brush is to reverse this current and bring it up to the correct amount in the opposite direction.

With copper brushes this reversal of current must be very accurately effected. With carbon brushes there is a much smaller tendency to spark, hence they will stand a certain inexactness of commutation adjustment. Experiments indicate that the carbon can resist as much as 3 volts creating current in the wrong direction and still not spark or glow. This is the property that has caused the use of carbon brushes instead of copper on most appa-

ratus. When, however, this potential, induced in the wrong direction, rises above 3 volts during the passage of the armature coil underneath the brush, trouble from sparking and glowing occurs.

This is the reason that, in a motor, the brushes are pulled backward as far as possible at no-load, so that the coil short-circuited by the brush may enter the fringe or flux from the pole-tip, thus creating the proper reversal of current during the time the coil is passing under the brush. Since adjacent poles are opposite in polarity, only one can provide the proper flux direction for this reversal. In a motor it is always the pole behind the brush and thus the brush requires a backward lead. In a generator it is the pole ahead of the brush in the direction of rotation. Hence generators require a forward lead.

If the motor gives trouble from glowing and pitting, the cause is probably this induced current, and the remedy is, first, to see that the lead of the brushes brings them in the most satisfactory position. If no change of lead or brush position can be found which will eliminate the trouble, the width of the brush must be changed. The wider the brush the longer does the coil suffer short-circuit, as described. Conversely the narrower the brush, the quicker must the current be reversed. There is, therefore, a width of brush which best satisfies both conditions.

Usually, however, where glowing occurs, the cause is too wide a brush, and often serious trouble from this cause can be entirely eliminated by varying the width of the brush perhaps only $\frac{1}{8}$ in.

72. **Sparking Due to Rough Commutator.**—First, the commutator surface may not be perfectly smooth after receiving its last turn off. The work may have been poorly done by the manufacturer, with the result that the commutator surface, instead of being left smooth, is somewhat rough. The result of this, especially with high-speed commutators, is that the brush does not make first-class contact with the commutator surface. It may chatter with attending noise, and thus with many motors (especially those of high voltage) the operation will be attended with sparking. As a result, the commutator surface, instead of becoming bright and smooth with time, becomes rough and dull or raw in appearance. Under these conditions the brushes do not make good contact, and, hence, the heat generated even under proper commutator conditions, owing to the resistance of brush contact, is multiplied several times, with consequent increase of temperature of the commutator. In addition, the friction of brush contact (which should give a coefficient of 0.2) is, with a rough commutator, much higher than it should be, which tends to increase the temperature.

73. **Heating of commutator** (*Westinghouse Instruction Book*) may develop from any of the following causes: (a) Overload; (b) sparking at the brushes; (c) too high brush pressure; (d) lack of lubrication on commutator.

74. **Hot Commutator.**—All this (see above) trouble is cumulative. The result is that finally the temperature will rise to a point where the solder in the commutator will melt, perhaps short-circuiting or open-circuiting the winding. A commutator will stand very slight sparking, but where it is noticeable and where

it is continued for long periods of time, trouble is liable to result. Where the load is usually very light on a motor, and where full-load or overload are infrequent, a smoothing of the commutator occurs during the light-load period which averts trouble. This is the reason that certain railway motors, which sometimes show sparking under their normal hour rating load, give satisfaction as to commutation. The coasting of the car smooths up the imperceptible damage done by the sparking during the heavy load.

75. Loose Commutator Segments.—A further and more serious cause of sparking and commutator trouble is due to the fact that the commutator may not be "settled" when shipped by the manufacturer. A commutator is made of many parts (Fig. 39), insu-

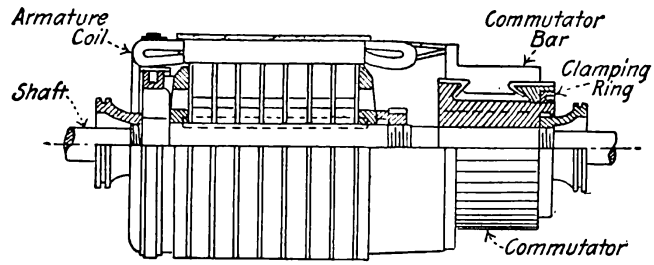


FIG. 39.—Section of direct-current motor armature.

lated one from another, and all bound together by mechanical clamping arrangements. The segments themselves are held by a clamp-ring on each end, which must be insulated from them and which should hold each segment individually from any movement relative to another.

Since the clamp must touch and hold down all segments, a failure to do so in any case results in a loose bar, which moves relatively to the next bar and causes roughness and thus sparking, with all its attendant accumulative troubles. The roughness of commutators due to poor turning or to poor design is shown uniformly over all the surface of the commutator on which brushes rest. A roughness due to a high or loose bar is shown by local trouble near the bad bar and its corresponding bars around the commutator. The jump of the brush occurs at the high bar and is the cause of the sparking. See also Pars. 77 and 78.

76. Blackening of the Commutator.—Sparking due to a loose or high bar causes a local blackening instead of a uniform blackening, which occurs in case of poor design or poor commutator surface resulting from poor turning. Also, if the speed of the commutator is low enough, there will be a spark at the time the bad segment passes the brush. At ordinary speeds, or where there are several loose bars, the sparking in appearance will not be different from that due to poor design or poor turning. In such a case an examination of the commutator surface must be made to identify the cause.

It must be remembered that the slightest movement of a bar, especially with the higher voltage and high-commutator-speed

machines, may cause the trouble. A splendidly designed motor may show very poor operation, due to a commutator fault.

77. Correcting Commutator Roughness.—The proper way to correct a rough surface due to poor turning is to grind the surface with a piece of ordinary grindstone (Fig. 40). It should be cut to convenient size and held by the hand against the commutator. If possible it should be rounded out to the shape of the commutator, though the rounding is not absolutely necessary except when the surface is exceedingly irregular. A commutator can be ground on low-voltage machines without removing the brushes from the commutator and during the ordinary operation of the motor under load. When sparking is due to poor turning, grinding causes the sparking to entirely disappear. This is also a good method of cleaning the surface of brushes which have become coated with copper from the use of sandpaper in fitting them to the commutator surface.

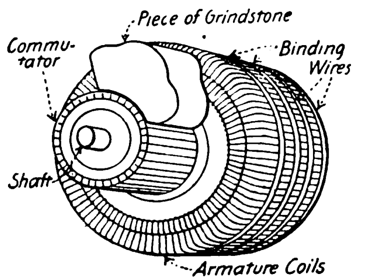


FIG. 40.—Smoothing commutator with grindstone.

Some kinds of sandpaper, if used to give a brush surface or to smooth a commutator with the brushes down, imbed in the face of the brush hard material which sticks there, cutting the commutator and thus collecting about itself copper from the commutator. An examination of the face of the brush after running a time will show these collections either in spots or all over the face of the brush. The sandstone, used as suggested, removes all this.

Where roughness and sparking are due to a loose bar, grinding will do no particular good. Then a different process for correction must be used. It consists first in tightening the clamp-rings which hold down the segments so that they touch and hold, each one preventing any relative movement of the bars. After this is done, produce a smooth surface by turning, if the bar is much displaced, or by grinding if it is but slightly displaced. The process of correcting a loose commutator therefore is as follows:

78. Loose Commutator. Clamp-rings.—First, draw the clamps of the commutator down firm, so that when the commutator is at normal temperature the clamping rings cannot be screwed down further without excessive effort. This is necessary so that all the bars may have a direct pressure from the clamp, rendering any movement, up or down, impossible. Second, after having drawn the clamps down, smooth off the surface of the commutator.

To get the clamps down firm run the motor; if roughness appears, shut down at a convenient time, and, while hot, tighten the clamping rings. If it is found that the tightening bolts can be screwed up somewhat, the machine should again be put in service for at least 4 hr., at the end of which time shut it down again and make another trial on the tightening bolts. If, now, no more can be taken up on the tightening bolts, the commutator should be surfaced, either by turning with a tool or by grinding. If the clamps

are down tight and the surface of the commutator has been properly smoothed, there will be no further trouble.

79. The Slotting of Commutators (*Alan Bennett*, *American Machinist*, Sept. 26, 1912).—There seems to be a prevalent idea that slotting should cure all commutator troubles, irrespective of their causes. This is not true, but slotting is a cure for certain specific troubles. Where the peripheral speed of the commutator is so slow that the dirt which may collect in the slots between commutator bars will not be thrown out by centrifugal force, slotting may aggravate rather than correct commutation difficulties. See also **84**.

80. The principal reason for slotting commutators is to relieve the commutators of high mica, that is, mica that projects above the surface. High mica is generally due to one of two causes: Either the mica is too hard and does not wear down at an equal rate with the copper, or the commutator does not hold the mica securely between the segments, allowing it to work out by the combined action of centrifugal force and the heating and cooling of the commutator.

It is evident that a commutator with a surface made irregular by projecting mica rotating at high speed under a brush, must impart to the brush a vibratory action, and thus impair the close contact that should exist between the brush and commutator. The result is that sparking takes place more or less violently, depending on the condition of the commutator surface and the rate of speed.

This condition generally manifests itself after the machine has been running for some time, and in many cases will account for the development of sparking which did not occur at the time of installation. Often a case of this kind is aggravated by increasing the brush tension, causing a still faster rate of wear of copper over mica, with an attendant increased heating of the commutator.

81. What is Accomplished by Slotting.—A harder brush may at times be used, with the idea of grinding off the mica and thus bringing it down to the commutator surface. Instead of curing the trouble, the commutator will, in the majority of cases, assume the raw appearance of being freshly sandpapered, instead of the glossy surface it should have, and both brush and commutator will wear rapidly.

This condition can be restored to normal and the commutator kept to a true surface by slotting, after which, with proper care and the use of proper brushes, commutator troubles will generally cease, provided the electrical design of the machine is not at fault. Even then there are cases that may be benefited to a certain extent by slotting, by reason of the good brush contact obtained. The majority of cases that show improvement are the ones in which the trouble is not inherent in the design of the machine, but is due to mechanical causes.

With a slotted commutator it is possible to use a brush of fine grain and soft texture, inasmuch as there is not the same tendency to wear away the brush as with an unslotted commutator. The commutator will then take on the much-desired polish that is

generally not possible with the harder brush. The life of both brush and commutator will be increased, and friction and the consequent heating will be reduced. These advantages will effect a saving that will more than offset the cost of slotting.

82. **Various Methods of Slotting.**—There is a variety of slotting devices on the market. Some are designed to operate with the armature swung between the centers of a lathe; others use a special tool in a shaper, with the armature secured to its bed. Still others are used by hand with the armature resting on blocks. In all cases the full width of the mica should be removed, and the resulting slot carefully cleaned from burrs and rough edges. It is not necessary that the slotting be carried deeply in the commutator. One-sixteenth of an inch is generally considered sufficient. See also Par. 84.

83. **A slotted commutator should have proper and frequent care,** as there is a chance of small particles of copper being dragged across from bar to bar, and for dirt, oil and carbon dust to accumulate in the slots and short-circuit the commutator.

84. **High Mica in Commutators.**—Some motors, under certain conditions, roughen up their commutators after a short term of service, although there seems to be no excessive sparking under or at the edges of the brushes. This may occur even though the commutator has been well "settled." The commutator acts as if the mica used between bars to insulate the various segments, one from another, had protruded upward, causing roughness and excessive sparking.

Actual raising of the mica is a very rare occurrence, and, if it occurs, does so at certain spots and is easily and positively identified. An actual uniform protruding of mica, all over a commutator, as described, is practically an unknown phenomenon. What actually does occur is an eating away of the copper surface of the commutator, leaving the high mica between the bars. A good machine will not spark enough to cause this condition. A poor machine will.

The phenomenon is easily identified, as the commutator surface looks raw all over instead of smooth and bright with a good brown gloss. If allowed to continue, a general roughness appears, accompanied by sparking, until finally the sparking and heating will increase so much that the machine may flash over from brush to brush, blowing the fuses or opening the circuit-breakers. The trouble is aggravated if the motor operates continuously under heavy load. If there are periods of light load, the commutator has an opportunity to be smoothed down by the brushes. This condition is appreciated by railway motor designers. A railway motor coasts a considerable portion of the time. Thus the commutator is smoothed, neutralizing the roughening occurring under load.

To remedy a roughened, high-mica commutator: (1) Use it on work where the load is somewhat intermittent; (2) replace it altogether; or (3) slot the commutator. Then, as there are no longer two different materials to wear down or to be worn away by sparking, an unequal surface will not result. The mica need

be cut down only $\frac{1}{16}$-in. and a narrow, sharp chisel will do the work satisfactorily. No trouble will result from short-circuiting in this case, since centrifugal force keeps the slots clean. Some manufacturers ship machines with slotted commutators.

85. Brush Troubles.—When there is an excessive drop in speed from no-load to full-load, the position of the brushes on the commutator should first be investigated as elsewhere suggested. No brush position that causes sparking should be chosen. The following paragraphs outline the more important brush troubles and their remedies.

86. Sparking of the brushes may be due to one of the following causes (*Westinghouse Instruction Book*). (See also Dynamo-defects Table.) (a) The machine may be overloaded; (b) the brushes may not be set exactly at the point of commutation—a position can always be found where there is no perceptible sparking, and at this point the brushes should be set and secured; (c) the brushes may be wedged in the holders; (d) the brushes may not be fitted to the circumference of the commutator; (e) the brushes may not bear on the commutator with sufficient pressure; (f) the brushes may be burnt on the ends; (g) the commutator may be rough; if so, it should be smoothed off; (h) a commutator bar may be loose or may project above the others; (i) the commutator may be dirty, oily or worn out; (j) the carbon in the brushes may be unsuitable; (k) the brushes may not be equally spaced around the periphery of the commutator; (l) some brushes may have extra pressure and may be taking more than their share of the current; (m) high mica; (n) vibration of the brushes.

These are the more common causes, but sparking may be due to an open circuit or loose connection in the armature. This trouble is indicated by a bright spark which appears to pass completely around the commutator, and may be recognized by the scarring of the commutator at the point of open circuit. If a lead from the armature winding to the commutator becomes loose or broken it will draw a bright spark as the break passes the brush position. This trouble can be readily located, as the insulation on each side of the disconnected bar will be more or less pitted. The commutator should run smoothly and true, with a dark, glossy surface.

87. Glowing and Pitting of Carbon Brushes.—This may be due to either of two causes, poor design or a wrong position of the brushes on the commutator. The error of design may be only in the choice of width of carbon brush used. The pitting is due to glowing. If the glowing is at the edge of the carbon it is plainly visible and easily located. It may, however, occur underneath the carbon so that only with difficulty can it be seen. Such glowing pits the carbon face by heat disintegration. With some machines three-fourths of the brush face may be eaten away and the pits may be, perhaps, $\frac{1}{4}$ in. to $\frac{1}{2}$ in. deep when discovered. A usual (incorrect) decision is that the current per sq. in. of contact is too great, the calculation being made by dividing the *line amp.* by *the sq. in. cross-section of either the positive or the negative brushes.* If this calculation gives a value under 45 or

50, it is certain that the cause of the trouble has not been judged correctly.

The real cause of the glowing is, to be sure, excessive current through the carbon, but this is not the line current if the calculation, as stated, shows a brush-face density below 50 amp. per square inch. It is a local current caused by the short-circuiting of two or more segments of the commutator by the brush resting upon them. The usual overlap of a carbon brush is about two segments, and while these two segments are under the brush, the armature coils connected to them are short-circuited. If the design of the machine is such that the coil so short-circuited encloses stray flux from the pole-tip, this flux will create in the short-circuited coil a current, perhaps many times larger than the brush is capable of carrying, with the result that the glowing and pitting occurs.

88. Chattering of brushes is sometimes experienced on direct-current machines. Chattering under certain conditions may become so prominent as to not only be of annoyance, but as to actually break the carbons. An examination of the commutator will reveal no roughness, the surface being, perhaps, perfectly smooth and bright. This trouble occurs principally with the type of brush holder which has a box guide for the carbon. The spring which forces the brush into contact rests on top of the carbon which has fairly free play in the box guide. Chattering usually occurs with high-speed commutators, running at 4,000 to 5,000 ft. per min., peripheral speed.

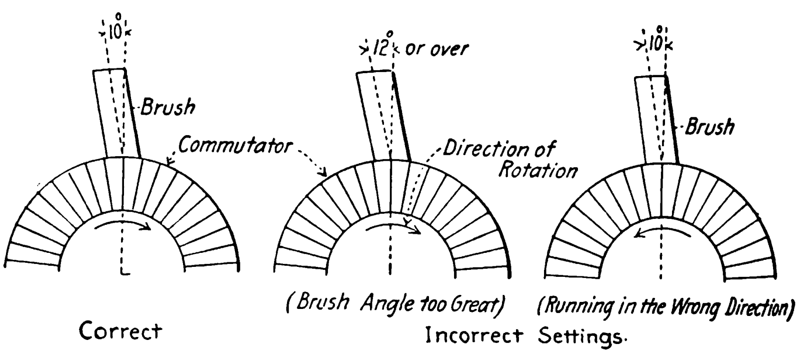


FIG. 41.—Methods of setting brushes.

Such brush holders are necessary on commutators which, like those on engine-driven machines, may run out of true on account of the shaft play in the bearings caused by the reciprocating motion of the engine. The clamped type of holder is usually free from bad chattering but rocks on a commutator that runs out, causing poor contact and perhaps sparking.

Lubricating the commutator causes the chattering to immediately disappear, but there is no commutator compound which gives a lubricating effect lasting over possibly a half hour. Thus it is not practical to lubricate often enough to prevent the chattering. There will be no chattering if the angle of the brush with the radial line, passing through the center of the carbon and the center

of the commutator, is less than 10 deg. and if the carbon trails on the commutator instead of leads. Fig. 41, *I*, shows the setting which will stop all serious chattering and Fig. 41, *II* and *III*, show settings which may give trouble.

89. Low Speed.—The fault may be in the winding of the armature or field, in which case a remedy is a serious matter. On the other hand, considerable range of speed can be obtained by the choice of brush position on the commutator. Many motors will run without sparking with a range or brush shift on the commutator giving a range of speed of 15 per cent. Therefore, if the discrepancy of speed is within this amount, the brushes should be moved to counteract it. A backward shift of brush gives increased speed and a forward shift decreased speed. At any brush position, however, there must be practically no sparking. Sparking is a very serious matter, causing all sorts of trouble. A first-class motor should run at full-load within 4 per cent. (up or down) of the name-plate speed if the voltage is as specified on the name-plate. The speed at no-load should not be more than 5 per cent. higher than this, also the speed at full-load, hot, should not be over 5 per cent. greater than the speed at full-load, cold.

90. Bearing Troubles of Direct-current Motors and Generators.—See paragraphs under this same heading under "Troubles of Alternating-current Motors and Generators."

PRINCIPLES, CHARACTERISTICS AND MANAGEMENT OF ALTERNATING-CURRENT MOTORS AND GENERATORS

91. Alternating-current generators are discussed in an elementary way in the preceding section. See Index. Modern

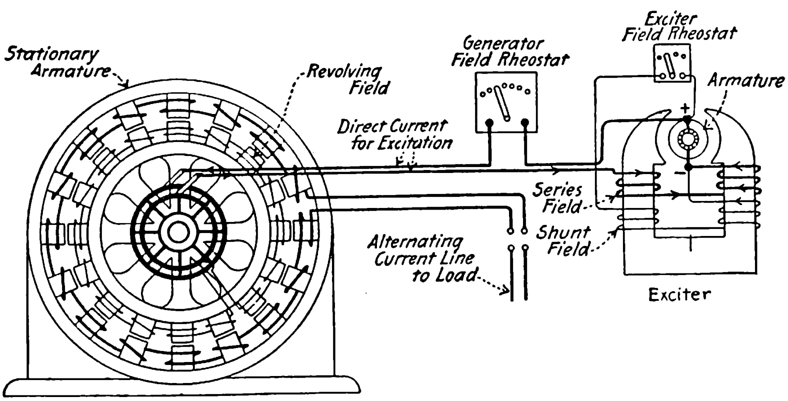


FIG. 42.—Elementary diagram of alternator and exciter.

commercial alternating-current generators usually are arranged as suggested diagrammatically in Fig. 42. Electromagnets, excited by a small direct-current generator or exciter, are mounted on a wheel-like structure which revolves within a circular stationary frame in the inner surface of which are armature coils. The re-

volving part is the revolving field; the stationary part is the armature. The direct current is fed to the field coils through collector rings. Armature coils are, in practice, arranged in slots in the inner circumference of the armature structure. Alternating e.m.fs. are induced in the armature by the lines of force from the field magnets cutting the armature coils. The alternating voltage can be varied, within limits, by adjusting the field rheostats.

92. **There are several types of alternators** or alternating-current generators. They are: (1) Revolving armature alternators wherein the armature revolves and the field magnets are stationary; (2) revolving field alternators, wherein the field magnets revolve and the armature is stationary; (3) inductor alternators, wherein both field magnets and armature are stationary and iron cores revolve between the armature core and the field-magnet poles. Modern alternators are practically all of the revolving field type because the stationary armature offers better opportunity for insulation and a high voltage is not necessary on the collector rings.

93. **The electromotive force in an alternator is generated as suggested in Fig. 43.** As each field coil, *D* for instance, sweeps past the armature coils the lines of force from the field coil cut the armature coils. As coil *D* passes from *A* to *C* an alternating e.m.f. represented by the curve *ABC* will be generated in the armature. It should be understood that in commercial alternators the armature coils are set in slots and differently arranged than in Fig. 43, which only illustrates a principle.

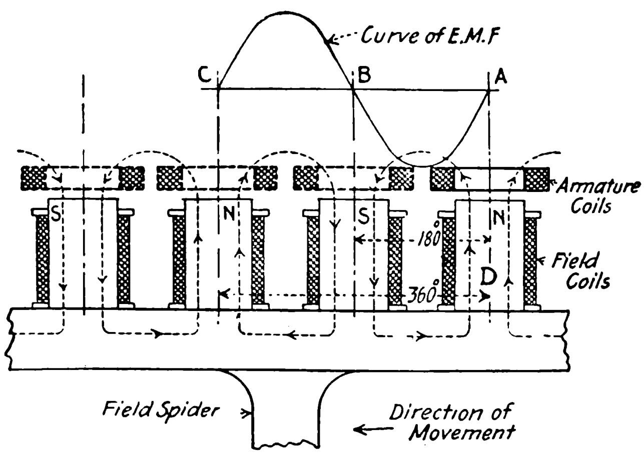


FIG. 43.—Armature and field structure developed.

94. **The speed and number of poles of an alternator or an alternating-current motor determine its frequency and vice versa.** (See Table 97.)

$$f = \frac{p \times \text{r.p.m.}}{120}; \text{ or } p = \frac{120 f}{\text{r.p.m.}}; \text{ or r.p.m.} = \frac{120 f}{p}$$

Wherein f = frequency in cycles per second, r.p.m. = revolutions per minute of rotor and p = the number of field poles.

Example.—What is the frequency of a two-pole alternator running at 3,600 r.p.m.?

Solution.—Substitute in the formula:

$$f = \frac{p \times \text{r.p.m.}}{120} = \frac{2 \times 3{,}600}{120} = \frac{7{,}200}{120} = 60 \text{ cycles per second.}$$

Example.—How many poles has a 25-cycle alternator running at 500 r.p.m.?

Solution.—Substitute in the formula:

$$p = \frac{120\,f}{\text{r.p.m.}} = \frac{120 \times 25}{500} = \frac{3{,}000}{500} = 6 \text{ poles.}$$

95. Single-phase Alternators.—The circumferential distance from the center line of one pole to the center line of the next pole of the same polarity constitutes 360 magnetic degrees. See Fig. 43, which shows how a single-phase e.m.f. is generated. Fig. 42 is a diagrammatic illustration of a single-phase alternator and Fig. 44 shows, diagrammatically, two different kinds of single-phase windings. Single-phase alternators are seldom made now. The

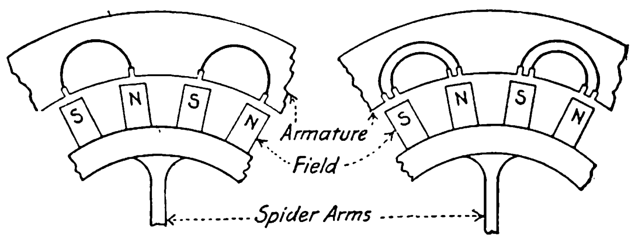


FIG. 44.—Single-phase armature windings.

manufacturers furnish three-phase machines instead and give them a single-phase rating equal to about 70 per cent. of the three-phase rating. The single-phase load is carried on any two of the three leads of the three-phase generator. See "Three-phase Alternator."

96. Approximate Performance Values

220, 440, 600, 1,100, 2,200 and 2,400

It should be understood that values will vary somewhat with mate only and do not apply to any particular manufacturers' line.

A slow-speed machine is assumed to be one turning at from 100 200 r.p.m. to 300 r.p.m., and a high-speed machine, one turning slow speed; "M" medium speed, and "H" high speed.

Kva output		Current							
		Three-phase						Two-phase	
		240 volts	480 volts	600 volts	1,200 volts	2,200 volts	2,400 volts	240 volts	480 volts
50	S M H	120.3	60.1	48.0	24.0	13.2	12.0	104.2	52.1
75	S M H	180.4	90.2	72.2	36.1	19.7	18.0	156.3	78.1
100	S M H	240.6	120.3	96.2	48.1	26.3	24.1	208.3	104.2
125	S M H	301.0	150.0	120.0	60.1	32.8	30.1	261.0	130.0
150	S M H	360.8	180.4	144.3	72.2	39.4	36.1	312.5	156.3
200	S M H	481.1	241.6	192.4	96.2	52.5	48.1	416.7	208.3
300	S M H	723.0	362.0	289.0	145.0	79.2	72.0	625.0	313.0
400	S M H	962.0	481.0	385.0	192.0	105.0	96.2	833.0	417.0
500	S M H	1203.0	602.0	481.0	241.0	132.0	120.0	1042.0	521.0
600	S M H	1450.0	722.0	578.0	289.0	158.0	144.0	1250.0	625.0
700	S M H	1690.0	841.0	673.0	337.0	184.0	168.0	1460.0	729.0
800	S M H	1930.0	977.0	773.0	387.0	211.0	193.0	1670.0	834.0
1,000	S M H	2406.0	1203.0	962.0	481.0	263.0	241.0	2083.0	1042.0
1,250	S M H	3000.0	1500.0	1200.0	600.0	328.0	300.0	2600.0	1300.0
1,500	S M H	3640.0	1804.0	1443.0	722.0	394.0	361.0	3130.0	1563.0
2,000	S M H	4850.0	2420.0	1924.0	962.0	526.0	481.0	4170.0	2080.0

of Alternating-current Generators

volts. Two-phase and three-phase.

speed and other conditions. Those given are general and approxi-

r.p.m. to 200 r.p.m.; a medium-speed machine, one turning at from at from 300 r.p.m. to 1,200 r.p.m. In the table, "S" indicates

Current				Efficiency			Exciter capacity required
Two-phase							
600 volts	1,200 volts	2,200 volts	2,400 volts	½ load	¾ load	Full-load	
41.7	20.8	11.3	10.4	.... [1]85.5 86.6	.... [1]88.0 89.8	.... [1]89.0 90.8	.... 7.0 2.0
62.5	31.3	17.2	15.6	.... [1]88.0 87.1	.... [1]90.0 89.7	.... [1]91.3 90.8	.... 8.0 3.0
83.3	41.7	22.8	20.8	.... [1]89.0 87.7	.... [1]91.0 90.2	.... [1]92.0 91.3	.... 9.0 3.0
104.0	52.1	28.4	26.1	.... [1]91.0 90.1	.... [1]92.0 91.7	.... [1]92.5 92.7	.... 9.0 5.0
125.0	62.5	34.1	31.3	[1]90.5 [1]91.0 90.2	[1]91.7 [1]92.0 91.8	[1]92.2 [1]93.0 92.8	14.0 9.0 4.5
166.7	83.3	45.5	41.7	[1]90.7 [1]91.0 90.1	[1]92.3 [1]93.0 92.7	[1]93.4 [1]93.5 93.5	12.0 11.0 6.0
250.0	125.0	68.1	63.0	[1]91.0 [1]92.0 89.2	[1]93.0 [1]93.5 92.1	[1]93.5 [1]94.2 93.2	20.0 15.0 12.0
333.0	167.0	91.0	83.3	[1]92.0 [1]92.0 90.2	[1]93.0 [1]94.0 92.3	[1]94.0 [1]94.5 93.8	23.0 14.0 12.0
417.0	208.0	113.0	104.0	[1]92.5 91.8 90.8	[1]94.0 93.5 93.5	[1]94.5 94.4 94.5	23.0 16.0 13.0
500.0	250.0	136.0	125.0	[1]92.5 92.4 90.0	[1]94.0 94.1 92.4	[1]94.5 94.8 93.8	28.0 22.0 20.0
583.0	292.0	159.0	146.0	[1]93.0 91.8 90.0	[1]94.0 94.1 92.5	[1]94.6 95.0 94.0	35.0 24.0 20.0
667.0	333.0	185.0	167.0	[1]92.8 92.1 91.5	[1]94.5 94.0 93.0	[1]95.3 95.0 94.0	32.0 23.0 17.0
833.0	417.0	228.0	208.0	[1]93.0 92.3 92.5	[1]94.0 94.2 94.0	[1]94.8 95.0 94.6	35.0 29.0 25.0
1040.0	520.0	384.0	260.0	[1]93.5 92.5 92.0	[1]94.5 94.6 94.2	[1]95.7 95.5 95.3	38.0 30.0 26.0
1250.0	625.0	341.0	313.0	[1]93.6 92.2 93.0	[1]94.7 94.4 95.1	[1]95.4 95.5 95.9	42.0 38.0 22.0
1667.0	833.0	455.0	417.0	[1]94.0 92.6 92.3	[1]95.0 94.8 94.7	[1]95.8 95.8 95.7	50.0 42.0 38.0

[1] **Engine type machines—efficiencies do not include friction of bearings.**

97. Synchronous Speeds—Alternating-current Generators and Motors

Application to Generators.—The table shows the speeds at which the rotor of an alternator which has a given number of field poles must turn to generate currents at given frequencies.

Application to Motors.—The table indicates the synchronous speed or the speed of the rotary magnetic field of an induction motor having a given number of poles and taking current at a given frequency.

The table also shows the speeds of synchronous motors having a given number of field poles and taking currents at given frequencies.

Number of poles	Revolutions per minute when frequency is											
	25	30	$33\frac{1}{3}$	40	50	60	$66\frac{2}{3}$	80	100	120	125	$133\frac{1}{3}$
2	1,500	1,800	2,000	2,400	3,000	3,600	4,000	4,800	6,000	7,200	7,500	8,000
4	750	900	1,000	1,200	1,500	1,800	2,000	2,400	3,000	3,600	3,750	4,000
6	500	600	667	800	1,000	1,200	1,333	1,600	2,000	2,400	2,500	2,667
8	375	450	500	600	750	900	1,000	1,200	1,500	1,800	1,875	2,000
10	300	360	400	480	600	720	800	960	1,200	1,440	1,500	1,600
12	250	300	333	400	500	600	667	800	1,000	1,200	1,250	1,333
14	214	257	286	343	428	514	571	686	857	1,020	1,071	1,143
16	188	225	250	300	375	450	500	600	750	900	938	1,000
18	167	200	222	267	333	400	444	533	667	800	833	889
20	150	180	200	240	300	360	400	480	600	720	750	800
22	136	164	182	217	273	327	364	436	545	655	682	720
24	125	150	167	200	250	300	333	400	500	600	625	667
26	115	138	154	185	231	280	308	370	423	554	577	615
28	107	128	143	171	214	257	286	343	429	514	536	571
30	100	120	133	160	200	240	267	320	400	480	500	533
32	94	113	125	150	188	225	250	300	375	450	487	500
36	83	100	111	133	166	200	222	266	333	400	417	444
44	79	82	91	109	136	164	182	218	273	327	341	363
48	63	75	83	100	125	150	167	200	250	300	312	333
54	56	66	74	90	111	133	148	178	222	266	278	296
60	50	60	67	80	100	120	133	160	200	240	250	266
68	44	53	59	71	88	106	118	141	176	212	221	235
72	42	50	55	67	83	100	111	133	166	200	208	222
96	31	38	42	50	64	75	82	100	125	150	156	167
100	30	36	40	48	60	72	80	96	120	120	150	160

98. Two-phase Alternator.—In a generator of the type indicated in Fig. 45 the centers of the two component coils *I* and *II* are situated 90 deg. apart and the single-phase electromotive forces generated in coils *I* and *II* by the passage of the field system past them, differ in phase by 90 deg. This property has given rise to the term quarter-phase for this type of machine, but it is more frequently called a two-phase machine. The electromotive force in coil *I* is zero when that in coil *II* is a maximum, and vice versa. The curves of electromotive force in coils *I* and *II* may be plotted as indicated in Fig. 46. Fig. 47 shows two methods of connecting

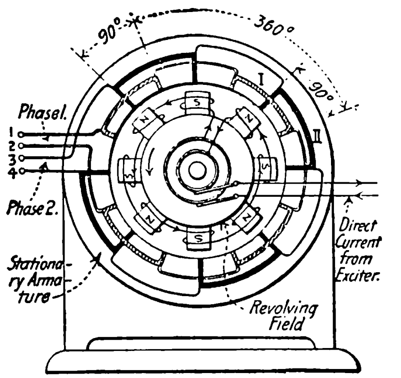


FIG. 45.—Diagram for two-phase alternator.

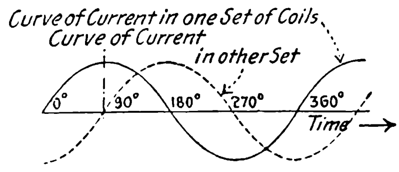


FIG. 46.—Curves of two-phase current.

the armature windings of two-phase alternators. The armature coils can be arranged in one or more slots per pole as diagrammatically suggested in Fig. 48. In commercial machines the windings are almost always arranged in more than one slot per pole. See first section for further information in regard to two-phase currents.

99. Three-phase alternator coils are arranged as illustrated diagrammatically by coils *I*, *III* and *II* of Fig. 49, and the curves of

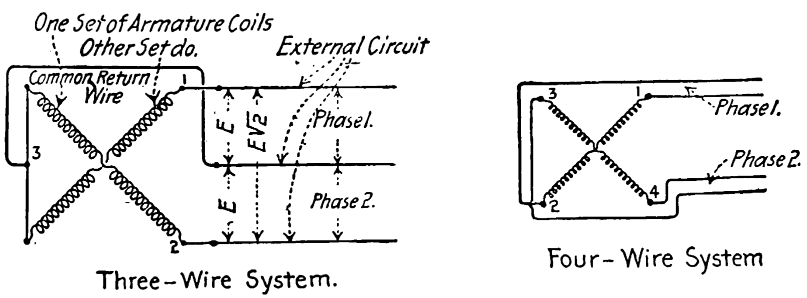


FIG. 47.—Methods of connecting two-phase generator armature windings.

instantaneous electromotive force are displaced from one another by 60 deg. as indicated in Fig. 51. This arrangement of coils is really a six-phase grouping, and in connecting the winding for three-phase, the coils of one of the phases must be connected in the reverse sense from the other two. This will give the true three-phase arrangement in which the e.m.f. curves are as in Fig. 52. These curves also represent the e.m.fs. for the winding in Fig. 50 with the three phases connected up in the same sense. Here

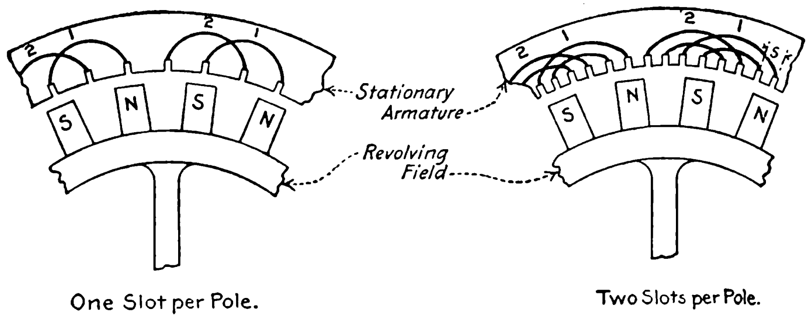


FIG. 48.—Two-phase armature windings.

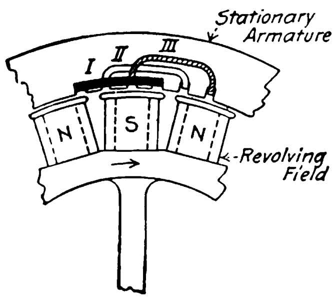


FIG. 49.—Six-phase grouping.

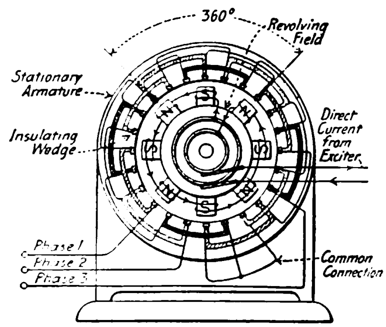


FIG. 50.—Diagram for three-phase, Y-connected alternator.

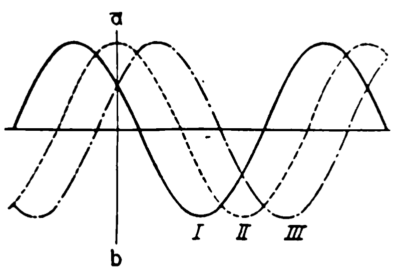


FIG. 51.—Curves of instantaneous electromotive forces.

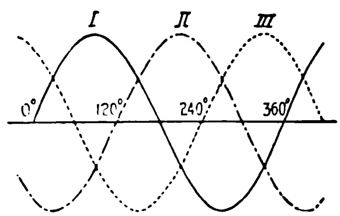


FIG. 52.—Curves of three-phase currents.

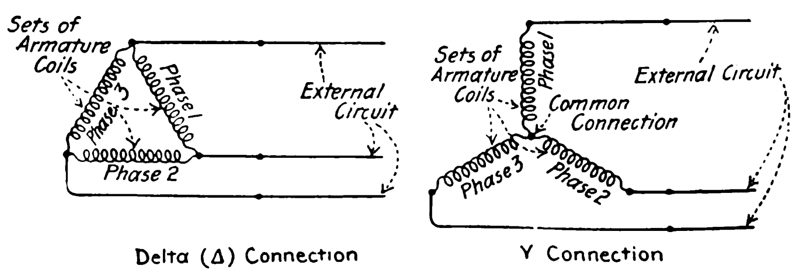


FIG. 53.—Methods of connecting three-phase armature coils.

three coils are distributed over a double pole pitch, and the phase displacement between the e.m.fs. is 120 deg.

The two methods of connecting three-phase armature windings are shown in Fig. 53. These methods are discussed in more detail in the first section. Armature windings can be arranged in one or more slots per pole (Fig. 54). The *Y* method of connection is almost always used for three-phase generators.

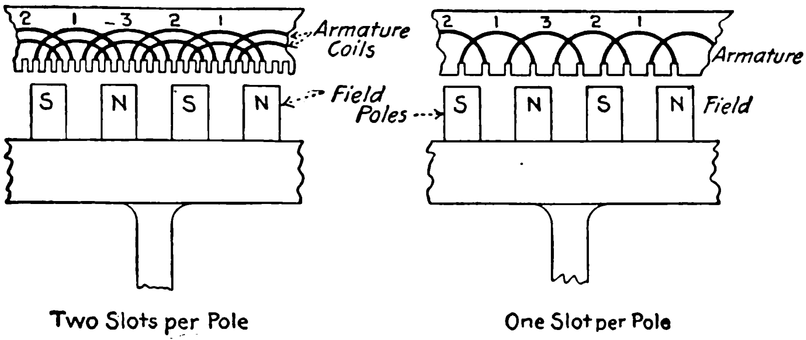


FIG. 54.—Three-phase armature windings.

100. Exciters for alternating-current generators (*Standard Handbook*) are usually compound-wound, flat-compounded, and rated at 125 or 250 volts. It is especially desirable that they be "stable," if direct-connected to the shaft of the alternators, as is sometimes done. By a stable generator is meant one that does not have an excessive rise or fall in potential with a corresponding change in speed. Standard direct-current machines of good design and of the desired rating are used where the exciters are separately driven, and separately driven exciters are preferable for most plants on account of the fact that the system is made much more flexible; any drop in the speed of the alternator does not cause a corresponding drop in the exciter voltage, and the regulation of the plant as a whole is improved. Furthermore, if the exciter is not direct-connected, an accident to it will not necessitate shutting down the generator, assuming that there is a duplicate exciter set.

In all cases it is necessary that the exciter capacity be ample and that there be sufficient reserve capacity. In order to make the exciter plant as reliable as possible, storage batteries are being installed in connection with the exciting generators in many plants in such a way that current may be furnished to the field circuits of the alternators, even though all rotating apparatus be at a standstill. As an example of the amount of reserve capacity that is sometimes installed: in the first power plant of the Niagara Falls Power Company four exciters are installed, each one having sufficient capacity to excite the entire plant, and each driven by its own turbine, fed by a separate penstock.

It is apparent that where separately driven exciters are used, the prime movers should be such that the exciters may be started independently of the current furnished by the alternators. Steam-

water-, or gas-driven units are necessary unless a storage battery or power from an external source is available for excitation of the plant when first starting up. With the bus-bars excited, motor-driven units may be operated and they are preferable in many cases. General figures for the capacity of an exciter for any machine run from 2.5 per cent. of the capacity of the alternator for moderate speeds and small sizes, to 0.5 per cent. of the alternator capacity, or a trifle less, for large, high-speed, turbine units. Two per cent. is a figure very commonly used in the absence of definite data. This is too low in a very few cases, but more often in error on the safe side.

101. **Synchronizing.**—(For a complete discussion of the various methods, and for diagrams of all synchronizing circuits in common use, for both lamps and synchroscopes, see *Electric Journal* articles by *Harold Brown*, May, 1912, and July, 1912.) Two or more alternating-current generators will not operate in parallel unless (1) their voltages, as registered by a voltmeter, are the same; (2) their frequencies are the same; and (3) their voltages in phase. If the machines are not in phase, even if their indicated voltages and their frequencies are the same the voltage of one will, at given instants, be different from that of the other and there will be an interchange of current between the machines. When two or more generators all satisfy the three above requirements they are in synchronism. Synchronizing is the operation of getting machines into synchronism. Incandescent lamps or instruments are, as described in other paragraphs used for indicating when machines are in synchronism.

102. **Synchronizing a Single-phase Circuit with Lamps.—The elementary principle** involved in determining synchronism is indicated in Fig. 55. If the voltage and frequency of generators *A* and *B* are the same and the machines are in phase, point *a* will be at the same potential at every instant as will point *a'*. Hence the lamps between *a* and *a'* will not light so long as the three conditions are satisfied. So long as the conditions are not satisfied there will be a fluctuating cross current from *a* to *a'* and a constant fluctuating of the brilliancy of the incandescent lamps. When the lamps become dark and remain so, the generators are in synchronism and may be thrown together. Had the connection at *a'* been made to the *b'* generator lead, the lamps would be bright when the generators were in synchronism, but for reasons outlined in another paragraph the connection shown which provides the "dark lamp" method of synchronizing is preferred. The second pair of lamps between *b* and *b'* is provided to insure against accident in case the *a*—*a'* set were broken. The same conditions occur in the *a*—*a'* set as in the *b*—*b'*

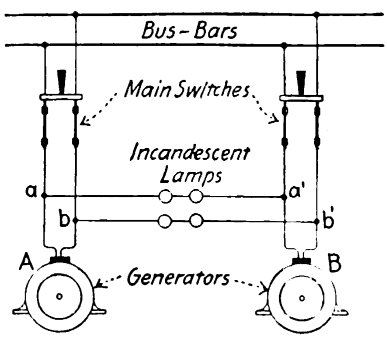


FIG. 55.—Circuits for synchronizing with lamps.

set. A voltmeter of proper rating can be substituted for the lamps.

Where the voltage generated is so high that it is not desirable to connect a sufficient number of lamps in series for it, a single lamp fed through voltage transformers can be used for synchronizing, as suggested in Fig. 56.

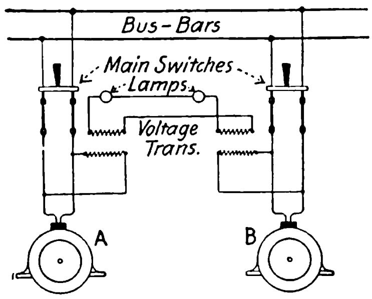


FIG. 56.—Circuits for synchronizing high-voltage circuits with lamps.

103. Phasing Out Three-phase Circuits.—Prior to connecting the leads from a polyphase generator, that is to operate in parallel with others, to the generator switch, the circuits must be "phased out." That is, the leads must be so arranged that each lead from the generator will, when the generator switch is thrown, connect to the corresponding lead of the other generator. If this is not arranged there may be considerable damage done due to an interchange of current when the two machines are paralleled. After once phasing out it is necessary to synchronize but one phase of the machine with the corresponding phase of the other machine.

Connections for phasing out three-phase circuits are shown in Fig. 57. If voltage transformers are not used the sum of the vol-

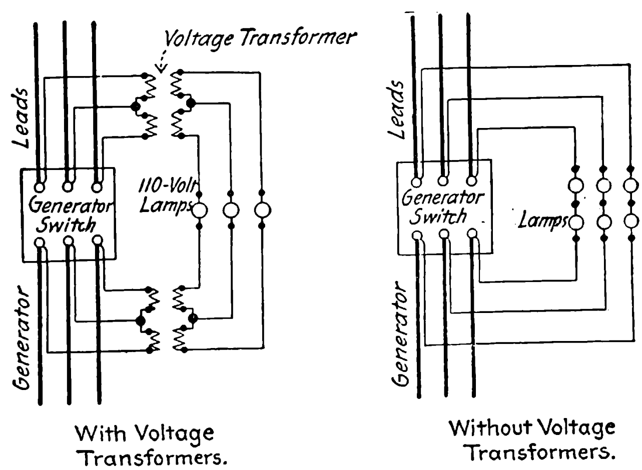


FIG. 57.—Connections for phasing out three-phase circuits.

tages of the lamps in each line should be approximately the same as the voltage of the circuits. On 440-volt circuits, two 220-volt or four 110-volt lamps should be used in each phasing-out lead.

To phase out, run the two machines at about synchronous speed. If the lamps do not all become bright and dark together, interchange any two of the main leads on one side of the switch, leaving the lamps connected to the same switch terminals, after which the lamps

should all fluctuate together and the connections are correct. The machines are in phase when all the lamps are dark.

104. **The synchronizing connections for three-phase generators** are shown in Fig. 58. A synchronizing plug may be used instead of the single-pole synchronizing switch shown. The illustration indicates the connections used where machines are to be synchronized to a bus. Where only two machines are to be synchronized, the connections are the same as shown in Fig. 58, except that the bus transformer and the corresponding lamp are omitted and one plug is required instead of two.

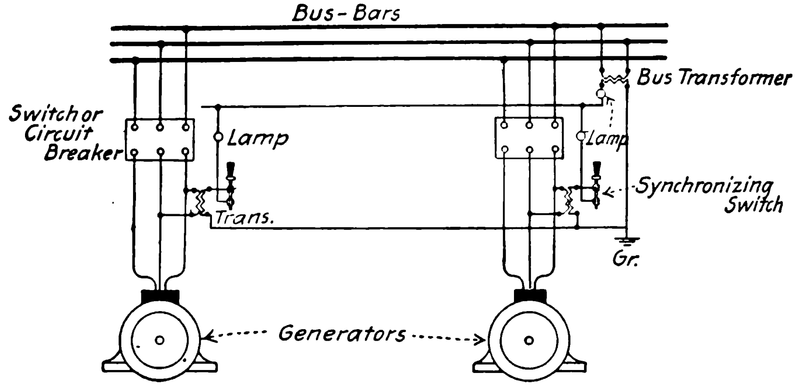


FIG. 58.—Connections for synchronizing three-phase circuits where transformers are required.

105. **Synchronizing Dark or Light.**—Synchronizing dark appears to be the preferable method. All the connections shown are for "synchronizing dark." When the lamps are "dark" the machines are in phase and it is necessary to close the switch when the pulsation is the slowest obtainable or ceases altogether, that is, at or just before the middle of the longest dark period.

Should a filament break the synchronizing lamps would remain dark and thus apparently indicate synchronism and possibly cause an accident. Therefore it is considered desirable by some to reverse the synchronizing circuit connections and thereby synchronize "light." Synchronizing light eliminates the danger due to the breaking of a filament, but has the disadvantage that the time of greatest brilliancy is difficult of determination. The "light" period is relatively long compared with the dark period so that synchronizing light is usually considered the more difficult and were it not that with the "synchronizing light" method the danger due to filament breakage is eliminated, the method would never be used.

The probability of a filament breaking just at the time of approaching synchronism and when the machines are not in phase is remote. If it occurs at any other time in the operation it will be noticed. As a protection against accidents due to breakage, two synchronizing lamps should always be placed in multiple.

106. **The number of lamps to use in a group to indicate synchronism** is determined by the voltage of the generators. With high voltage circuits it is not feasible to use a sufficient number of lamps, so a transformer is employed that has a voltage sufficient for a 110-volt lamp. See the diagrams. The greatest voltage impressed on the lamps is double that of the voltage transformers or generators. Thus the maximum voltage on the lamps where two 220-volt generators are being synchronized is 440 volts. The dark period may be shortened by impressing a voltage higher than their normal on the lamps. For two 220-volt machines, for example, three 110-volt lamps might be used.

107. **Synchroscopes** are instruments that indicate the difference in phase between two electromotive forces at every instant. They show whether the machine to be synchronized is running fast or slow and indicate the exact instant when the machines are in synchronism. The companies that manufacture the instruments furnish literature describing the theory involved and that gives complete circuit diagrams.

108. **While for successful parallel operation,** it is not necessary that alternating-current generators be of the same type, output, and speed, it is universally conceded that the question of wave shape is important, since if the waves are of different shapes, cross currents will always be present. Similar wave shapes are more readily obtained with machines of similar type. Satisfactory parallel operation, the previously mentioned conditions being fulfilled, consists in obtaining:

(1) Correct division of the load amongst the machines; and

(2) Freedom from hunting.

109. **Division of Load.**—Machines with similar characteristics tend to divide the common load uniformly. Such a proportional load division may be disturbed if the steam supply to the engines is defective or variable from any cause. The steam supply is regulated by the engine governors, and defects in one or more of these governors will give rise to poor load division. It is essential that the governors of all the engines shall have similar speed-regulation characteristics so that a sudden change in the load shall cause the same amount of regulation on each engine. Correct load division is therefore essentially a problem for the engine governors. It is sometimes arranged to govern all the engines from a common throttle valve, but this plan is not often employed. A more usual plan consists in running all the machines except one, with their stop valves full open and their governors fixed, so that the remaining engine may take up any variations in the common load.

Varying the voltage of an alternator running in parallel with others by adjusting its field rheostat will not vary the load on it as with a direct-current generator. To increase the energy delivered by an alternator it is necessary that the prime mover be caused to do more work. An engine should be given more steam or a water-wheel more water.

110. **Adjustment of Field Current.**—When the rheostats of two alternators running in parallel at normal speed are not adjusted to give a proper excitation, a cross current will flow between the

armatures. The intensity of this current depends only upon the difference in field charges of the machines. It may vary over a wide range, from a minimum of zero when both field charges are normal, to more than full-load current when they differ greatly. The effect of this cross current is to increase the temperature of the armatures and, consequently, to decrease the output of the generators. It is important that the rheostats be so adjusted as to reduce it to a minimum. This cross current registers on the ammeters of both generators and usually increases both readings. The sum of the ammeter readings will be a minimum when the idle or cross current is zero.

In general, the proper field current for a machine running in parallel with others is that which it would have if running alone and delivering its load at the same voltage. In order to determine the proper position of the rheostats it is necessary to make trial adjustments after the alternators are paralleled, until that position is found at which the sum of the ammeter readings is a minimum.

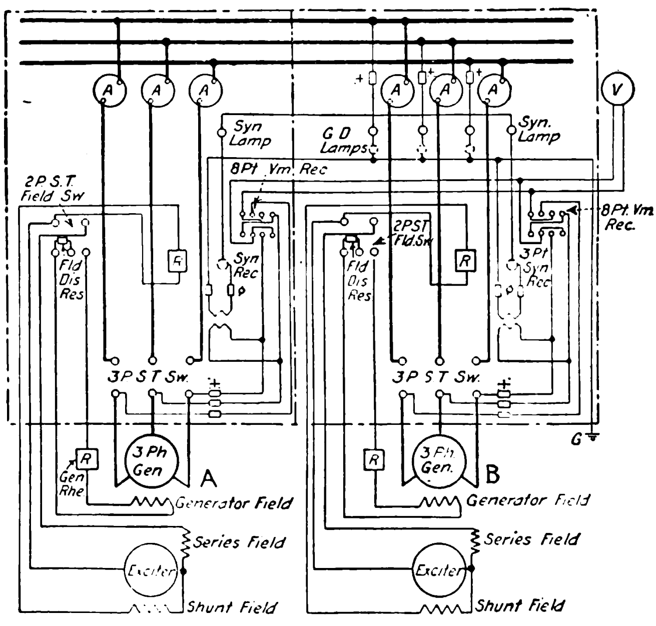


FIG. 59.—Two three-phase alternators of similar characteristics operating in parallel.

To illustrate this method let us consider two similar alternators, *A* and *B*, Fig. 59, operating in parallel. When the generator field rheostats of both are properly adjusted no cross currents will flow through the armatures and the main ammeters will show equal readings if each machine is receiving the same amount of power from its prime mover. If the rheostat of *A* be partly cut in so as to reduce its field current, a cross current, lagging in *B* and leading in *A*, will flow between the armatures, the effect of which will be to strengthen *A's* magnetization and weaken *B's* until they are approx-

imately equal. The resultant e.m.f. of the system will thereby be lowered.

On the other hand, if the rheostat of B be partly cut out so as to increase its field current, a cross current leading in A and lagging in B will flow between the armatures, strengthening A's magnetization and weakening B's magnetization until they are again equal. The resultant e.m.f. of the system will thereby be raised. A cross current of the same character is therefore produced by decreasing one field current or increasing the other, *i.e.*, in both cases it will lead in the first machine and lag in the second machine. The e.m.f. of the system will, however, be decreased in one case and increased in the other.

It is obvious that by simultaneously adjusting the two rheostats, the strength of the cross current may be varied considerably and the e.m.f. of the system maintained constant.

For the first trial adjustment cut in A's rheostat several notches and cut out B's the same amount, so as not to vary the e.m.f. of the system. If this reduces the sum of the main ammeter readings, continue the adjustment in the same direction until the result is a minimum. After this point is reached a further adjustment of the rheostat in either direction will increase the ammeter readings. If the first adjustment increases the sum of the ammeter readings it is being made in the wrong direction, in which case move the rheostats back to the original positions and then cut out A's rheostat and cut in B's. If both adjustments increase the sum of the ammeter readings the original positions of the rheostats are the proper ones.

In making these adjustments of the rheostats it may be found difficult to locate the exact points at which the cross current is a minimum, as it may be possible to move the rheostats over a considerable range when near the correct positions without materially changing the ammeter readings. When the adjustment is carried this far, it is close enough for practical operation. If the generators are provided with power factor meters, the same result may be obtained by adjusting all these to read the same.

111. **Hunting** (*Standard Handbook*) is a term employed to describe the oscillations of the revolving masses of the machines when they are accelerated and retarded above and below the normal average speed. If this hunting or swinging be allowed to exceed a certain amount, the regulation of the machines becomes unstable and they may break out of step. Freedom from cumulative hunting is consequently essential. The swinging action is set up primarily by variations in the rotative speed resulting from irregularity in the turning force. A perfectly uniform turning moment or turning force cannot be obtained with reciprocating engines. The irregularity in the turning moment during a revolution results from the following causes:

Defective distribution of steam in cylinders.

Short connecting rod.

Inertia of moving parts.

If one of two machines running in parallel momentarily lags behind the other, its armature receives a current which tends to pull

the machine into phase and accelerate it so that at the instant it reaches the correct phase position its speed is a little greater than that of the other machine, which is now in turn accelerated. The machines are now alternately lagging and leading with relation to one another. In other words, hunting is set up.

Whichever engine is, for the instant, accelerating, will have its steam supply cut down by the governor. If the governor is too sensitive, it will over-govern, cutting down the steam and the speed too far. An instant later, the over-governing will be in the opposite sense, and this process will repeat itself. Similar occurrences will simultaneously be taking place on the other engine, and thus we have a case of hunting governors. By this hunting, the steam supply is rendered periodic and varies between two limits.

112. **Surging** is the term used in connection with the current variations during the hunting, the latter term applying to the mechanical phenomenon of periodic speed variations. The case described is an instance of hunting in the governors due to change of load and to over sensitiveness of the governors. If, however, the governors are sluggish, a time interval elapses between an accidental acceleration and its correction by the governor. This lag will, in response, tend to set up hunting.

113. **Prevention of Hunting.**—The variations in turning moment and angular speed may be greatly reduced by the use of a heavy flywheel, as this tends to keep the rate of revolution uniform by virtue of storing energy and giving it out again during the course of each revolution. The flywheel, however, must not have too great a moment (that is, it must not be too big) as it adds to the inertia of the moving parts and may prolong hunting if once started. Hunting may sometimes be overcome by damping the governor so that it shall not respond to small and quick variations in speed such as occur during one revolution, but shall only respond to steady and continued changes in speed. This result is obtained by fitting each governor with a suitable dash-pot so that it is rendered more sluggish and will make no alteration in the steam supply except when the force acting on the governor is continued for some length of time.

Liability to hunt may sometimes be prevented by synchronizing the engines so that the cranks on all the engines are in step, and the variations in turning moment are coincident in all the engines. This plan is sometimes effective, so far as the prevention of hunting in the generating station is concerned, but it cannot always be utilized owing to the time taken to get the cranks in step, especially as an engine must be run up in a few minutes when the load is coming on quickly. It also is apt to intensify the hunting of the apparatus in distant sub-stations.

With steam turbine-driven generators, this hunting difficulty is much more rare—practically unknown—and the use of high and uniform speeds facilitates the problem of parallel running.

The tendency of generators to hunt may be minimized by surrounding the pole pieces of the field magnets with copper bands in which eddy currents are induced by the shifting and distortion of the field. These currents react on the field and oppose the shift-

ing and thus damp the oscillations. A more suitable construction consists of a grid of copper embedded in the pole face. It is very seldom necessary to provide such "dampers" on pole pieces of generators for modern steam-engine or waterwheel drive. They are usually necessary for gas-engine driven generators.

114. **To Start a Single Alternator.**—(1) See that there is plenty of oil in the bearings and that the oil rings are free to turn and that all switches are open. (2) Start exciter and adjust for normal voltage. Start generator slowly. See that the oil rings are turning. (3) Permit the machine to reach normal speed. Turn the generator field rheostat so that all of its resistance is in the field circuit. Close the field switch. (4) Adjust the rheostat of the exciter for the normal exciting voltage. Slowly increase the alternator voltage to normal by cutting out the resistance of the field rheostat. (5) Close the main switch.

115. **To Start an Alternator to Run in Parallel with Others.**—(1) Bring the exciter and generator to speed as described in the above paragraph. Adjust the exciter voltage and close the field switch, the generator field resistance being all in. (2) Adjust the generator field resistance so that the generator voltage will be the same as the bus-bar voltage. (3) Synchronize, as outlined in one of the above paragraphs. Close the main switch. (4) Adjust the field rheostat until cross currents are a minimum and adjust the governors of the prime movers so that the load will be properly distributed between the operating units in proportion to their capacities.

116. **To Cut Out a Generator Which is Running in Parallel with Others** (*Westinghouse Instruction Book*).—(1) Preferably cut down the driving power until it is just sufficient to run the generator empty. This will reduce the load on the generator. (2) Adjust the resistance in the field circuit until the armature current is a minimum. (3) Open the main switch. It is usually sufficient, however, to simply disconnect the machine from the bus-bars, thereby throwing all the load on the remaining machine without having made any previous adjustment of the load or of the field current.

Caution.—The field circuit of a generator to be disconnected from the bus-bars must not be opened before the main switch has been opened; for, if the field circuit be opened first, a heavy current will flow between the armatures.

117. **The principle of operation of the induction motor** is illustrated in Fig. 60, which indicates diagrammatically a two-phase revolving field generator and a two-phase induction motor having a rotor that is simply a bar of iron. The induction motor depends for its operation on a rotating magnetic field. There is no electrical connection between the revolving and stationary parts of an induction motor.

Windings of the types shown in the illustration are not used in commercial machines, but the general theory involved is the same as with commercial windings. The revolving field (see illustration) of the generator, in turning in the direction shown by the arrow, generates a two-phase current which is transmitted to the motor.

The current, in conductors of one phase, magnetizes poles *A* and *B* and that in the other phase the poles *C* and *D*. The winding is so arranged that a current entering at *A* will produce a south pole at *A* and a north pole at *B*. At the instant shown at *I*, the motor poles *A* and *B* are magnetized while poles *C* and *D* are not, because it is a property of a two-phase circuit that when the current in one of the phases is at a maximum value, the current in the other phase is at a zero value. Hence, the bar iron rotor will assume the vertical position shown.

At another later instant, represented at *II*, the currents in both of the phases are equal and in the same direction; the motor poles will be magnetized as shown and the rotor will be drawn into the position indicated. At the instant illustrated at *III*, because of the properties of two-phase currents, there is no current in the phase the conductors of which are wound on poles *A* and *B*, but the current in the phase the conductors of which magnetize poles *C* and *D*, is a maximum. Hence the rotor is now drawn into a horizontal position. Similar action occurs during successive instants and the rotor will be caused to rotate in the same direction within the motor frame so long as the two-phase current is applied to the motor terminals. Considering it in one way, the rotating magnetic field rotates within the motor frame and drags the rotor around with it.

The magnetic attraction or drag exerted on the rotor in a simple motor built as illustrated would be pulsating in effect, hence the torque exerted by such a motor would not be uniform.

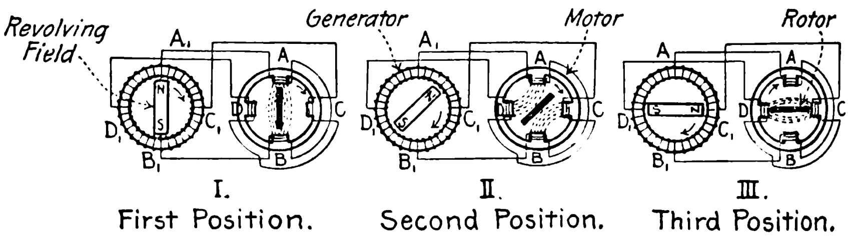


FIG. 60.—Illustrating the principle of the induction motor.

118. Commercial induction motors operate because of the principles outlined in **117**, but their construction is considerably different from that shown in Fig. 60. In commercial induction motors the stator or primary winding is distributed over the entire inner surface of that portion of the stator structure which is of laminated iron and which conducts the magnetic flux. The rotor consists of a laminated iron cylinder which has a winding of insulated wire or of copper rods or bars embedded in slots uniformly spaced around the periphery of the core. Where bars or rods are used they are short-circuited at both ends by heavy copper conductors forming a completely short-circuited rotor.

In the commercial induction motor the magnetic field of the rotor which reacts on the magnetic field of the stator is produced by currents in the rotor conductors. These currents are generated

by the rotor conductors being cut by the lines of force of the rotating field which was described in a preceding paragraph. Consider a polyphase induction motor with its rotor at rest. Now connect a source of the proper polyphase current to the motor terminals thereby energizing the stator winding. A rotating magnetic field will be produced by the stator winding. As this magnetic field swings around within the stator structure it will cut the copper bars imbedded in the surface of the rotor. Currents will thereby be induced in the bars and these currents will generate magnetic fields around and within the rotor. Due to the interaction between the rotor and stator magnetic fields, rotation of the rotor will be produced.

It is therefore evident that the turning speed (revolutions per minute) of the rotor can never be quite equal to that of the rotating magnetic field as there must always be a sufficient difference in speed or "slip" that the rotor conductors will be cut by the lines of force of the rotating field. Obviously, if the rotor speed were the same as that of the revolving field, no lines of force could be cut by rotor conductors and there would not be sufficient magnetic interaction between the stator and rotor fields to produce rotation of the rotor and pull a load.

The intensity of the current induced in the rotor and therefore the torque is determined by the amount of "slip" between the rotor and the rotating magnetic field. The greater the torque required, the greater will be the slip.

119. General Characteristics of Polyphase Squirrel-cage Induction Motors.—Their speed is practically constant at all loads. Hence they are used for constant-speed service where starting and reversing are infrequent. The starting torque is relatively small and a large starting current 2 to 6 times full-load current, depending on the design of the motor, is drawn from the line if the motor must start full-load torque.

Simple and rugged construction is a feature of these motors, the bearings being the only parts subject to wear. Since there are no sliding electrical contacts there can be no sparking and the motors are therefore particularly suitable for operation in places where there are inflammable gases or dust.

If the resistance of the rotor be increased the motors can be built, in the smaller capacities, for high starting torque, rapid acceleration, and frequent starting. Motors built thus can be profitably used for operating punches, shears and the like, where simplicity of control is desirable, as with them a large drop in speed produces but a slight increase in torque, permitting the stored energy in the flywheel to be delivered to the machine when a heavy load occurs. In this respect such an induction motor resembles a compound-wound direct-current motor.

If the torque imposed on any induction motor reaches 2 to 4 times full-load torque the motor will stop or "pull out." (See Par. 126.)

The output and torque of an induction motor varies as the square of the applied voltage, hence it is desirable to maintain the voltage at normal value.

120. Approximate Data on

220, 440 and 2,200 volts,[1]

The values given are general and approximate, but are fairly represen-

H.p.	Poles	Synchronous speed		Approx. full-load slip, per cent.		Approximate full-load speed		[2]Starting current for full-load torque
		25 cycles	60 cycles	25 cycles	60 cycles	25 cycles	60 cycles	
½	4	750	1,800	8	6	690	1,700	2.7-3
1	4	750	1,800	8	6	690	1,700	2.7-3
1½	6	500	1,200	8	7	460	1,120	2.7-3
2	4	750	1,800	8	6	690	1,700	2.7-3
2	**6**	**500**	**1,200**	**8**	**7**	**460**	**1,120**	**2.7-3**
3	4	750	1,800	8	6	690	1,700	2.7-3
3	6	500	1,200	8	7	460	1,120	2.7-3
4	8	375	900	8	6	345	850	2.7-3
5	4	750	1,800	8	6	690	1,700	2.7-3
5	**6**	**500**	**1,200**	**8**	**7**	**460**	**1,120**	**2.7-3**
5½	8	375	900	8	6	345	850	2.7-3
7½	4	750	1,800	7	4	700	1,720	2.7-3
7½	6	500	1,200	7	5	465	1,135	2.7-3
7½	8	375	900	7	6	349	850	2.7-3
10	**6**	**500**	**1,200**	**7**	**5**	**465**	**1,135**	**2.7-3**
10	8	375	900	7	6	349	850	2.7-3
12	10	300	720	6	6	282	680	2.7-3
15	6	500	1,200	6	5	470	1,135	2.7-3
15	10	300	720	6	6	282	680	2.7-3
20	**6**	**500**	**1,200**	**6**	**5**	**470**	**1,135**	**2.7-3**
20	8	375	900	6	6	353	850	2.7-3
25	6	500	1,200	6	5	470	1,135	2.7-3
25	12	250	600	5	6	237	565	2.7-3
30	8	375	900	5	6	355	850	2.7-3
35	**8**	**375**	**900**	**5**	**6**	**355**	**850**	**2.7-3**
35	12	250	600	5	6	237	565	2.7-3
40	8	375	900	4	6	360	850	2.7-3
50	8	375	900	4	6	360	850	2.7-3
75	10	300	720	4	6	288	680	3-3.5
75	**14**	**214**	**514**	**4**	**4**	**205**	**495**	**3-3.5**
100	10	300	720	4	4	288	690	3-3.5
110	16	....	450	....	4	......	430	3-3.5
150	12	....	600	....	4	......	575	3-3.5
150	16	....	450	....	3	......	435	3.5
200	**12**	....	**600**	....	**4**	......	**575**	**3.5**

[1] 2,200-volt motors are seldom if ever made for capacities of less than 20 to 30 h.p.
[2] Starting current for full-load torque in terms of full-load current.
[3] Starting torque in terms of full-load torque.

121. Characteristics of Polyphase Induction Motors Having Wound Rotors and Internal Starting Resistance.—Motors of this type of the ordinary design give about 1½ times full-load torque with approximately 1½ times full-load current, making them suitable for use on lighting circuits and for other applications where a minimum starting current is desirable. In general, motors of this type are not built in capacities exceeding 200 h.p. because of the mechanical difficulties encountered in arranging the internal resistance.

Standard Induction Motors

two-phase and three-phase.

tative of what may be expected from commercial induction motors.

[3]Starting torque at rated voltage	[4]Pull out torque	[5]Efficiency, per cent.				Power factor, per cent.				H.p.
		½ load	¾ load	Full-load	1¼ load	½ load	¾ load	Full-load	1¼ load	
1.3	2.3	65	70	72	73	52	63	70	72	½
1.3	2.3	74	77	77	76	60	72	80	83	1
1.3	2.3	82	84	84	83	60	72	78	80	1½
1.2	2.3	82	84	85	85	64	75	80	83	2
1.3	**2.3**	**82**	**84**	**84**	**83**	**60**	**72**	**78**	**80**	**2**
1.3	2.3	82	85	85	84	74	83	86	88	3
1.3	2.3	81	83	84	84	65	75	81	83	3
1.5	2.5	82	85	85	84	74	83	86	88	4
1.5	2.5	83	85	85	84	78	85	88	89	5
1.3	**2.5**	**84**	**86**	**86**	**85**	**78**	**84**	**86**	**87**	**5**
1.5	2.5	82	85	85	84	74	83	86	88	5½
2	3	83	85	85	84	79	88	90	92	7½
1.5	2.5	83	85	84	84	73	82	85	87	7½
1.5	2.5	83	85	85	85	70	78	83	85	7½
1.5	**2.5**	**85**	**86**	**85**	**84**	**80**	**86**	**89**	**90**	**10**
1.5	2.5	84	86	85	84	75	82	86	88	10
1.5	2.5	85	86.5	86	86	70	80	85	88	12
1.5	2.5	85	86	86	85	79	86	89	90	15
1.5	2.5	85	86.5	86	86	70	80	85	88	15
1.5	**2.5**	**87**	**88**	**87.5**	**87**	**82**	**89**	**91**	**90**	**20**
1.5	2.5	84	85	85	85	71	81	85	87	20
1.5	2.5	86	87	87	86	82	89	91	91	25
1.5	2.5	86	87	87	87	64	75	81	83	25
1.5	2.5	86	86.5	86	85	72	82	86	88	30
1.5	**2.5**	**87**	**88**	**88**	**87**	**72**	**82**	**86**	**88**	**35**
1.5	2.5	86	87	87	86	75	83	85	86	35
1.5	2.5	87	88	87	86	76	84	89	90	40
1.75	2.75	87	88	88	88	78	86	89	90	50
1.75	2.75	86	87.5	87	86.5	76	84	88	90	75
1.75	**2.75**	**86**	**88**	**89**	**89**	**74**	**83**	**87.5**	**89**	**75**
1.75	3	89	90	90	90	83	89	91	91	100
1.75	3	87	89	92	91	85	91	92	91	110
1.75	3	89	90	90	89	82	89	91	90	150
1.5	2.5	87	89	89	88	80	87	89	90	150
1.5	**2.5**	**91**	**92.5**	**92**	**91**	**85**	**91**	**92**	**91**	**200**

[4] Pull-out torque in terms of full-load current.

[5] Efficiencies of 25-cycle motors slightly lower than those of 60-cycle motors due to their lower speeds.

Compared with the squirrel cage motor, one with a wound rotor and internal resistance will develop a greater starting torque per ampere, but it should not be used for applications wherein there is great inertia or excessive static friction. If used for such applications full starting current may be required for a considerable period before the apparatus attains full speed. Since the capacity of the internal resistance is small, excessive temperatures may result and cause trouble.

122. Approximate Amperes per Terminal for Alternating-current Induction Motors

Horse-power	Single-phase			Two-phase (four wire)			Three-phase (three wire)					
	110 volts	220 volts	440 volts	110 volts	220 volts	440 volts	110 volts	220 volts	440 volts	550 volts	1100 volts	2200 volts
0.5	6.6	3.4	1.8	3.3	1.7	0.9	3.7	1.8	1	....	....	....
1	14	7	3.5	6.4	3.2	1.6	7.4	3.7	1.9	....	....	....
2	24	12	6	11	5.7	2.9	13	6.6	3.3	2.5	....	....
3	34	17	8.5	16	8.1	4.1	19	9.3	4.7	3.5	....	....
5	52	26	13	26	13	6.5	30	15	7.5	6	....	....
7.5	74	37	18.5	38	19	9.5	44	22	11	9	....	....
10	94	47	23.5	44	22	11	50	25	12.5	11	....	....
15	....	....	....	66	33	16.5	76	38	19	16	....	....
20	....	....	....	88	44	22	102	51	25.5	22	....	....
25	....	....	....	111	55	28	129	64	32	25	....	....
30	....	....	....	134	67	33.5	154	77	38.5	32	16	8
40	....	....	....	178	89	44.5	204	107	53.5	44	21	11
50	....	....	....	204	102	51	236	118	59	52	27	13
75	....	....	....	308	154	77	356	178	89	77	39	20
100	....	....	....	408	204	102	472	236	118	100	50	25
150	....	....	....	616	308	154	710	355	178	147	80	40
200	....	....	....	818	409	204	940	470	235	192	98	49
250	....	....	....	.....	510	250	.....	590	290	237	125	62
300	....	....	....	.....	600	300	.....	700	350	285	150	74

123. Characteristics of Polyphase Slip-ring or Wound-rotor Induction Motors Having External Starting Resistance.—These motors have insulated wire or bar windings on the rotor and are provided with collector rings whereby an external resistance can be connected in the rotor circuit. The speed of the motor can be varied by varying the amount of external resistance in the rotor circuit. These motors are used in moderate and large capacities for nearly all variable speed applications. They are also used for constant speed applications where the starting current must be low.

The motors operate with characteristics similar to those of direct-current motors having resistance in the armature circuit. When the external resistance is short-circuited, the motors really become squirrel cage machines and operate with the characteristics of such machines.

124. Characteristic Curves of the Induction Motor.—The curves of Fig. 61 are fairly typical of the average commercial induction motor. It will be noted that the normal rating of the motor is taken at such a point that both the power factor and the efficiency are the highest possible. The motor could be so designed that either the power factor or the efficiency, but not both, could be higher than shown at normal load, but the design of an induction motor is a compromise between the leading factors resulting in

the best efficiency and power factor obtainable with suitable overload and starting characteristics. Fig. 62 shows the curves of the same motor running single-phase.

125. The torque curves of an induction motor with a wound rotor, from rest to synchronism, running both three-phase and single-phase with resistance and without resistance, are shown in Fig. 63. Curve *A* shows the torque from rest to synchronism without resistance in the rotor circuit. If resistance is inserted, curve *B*

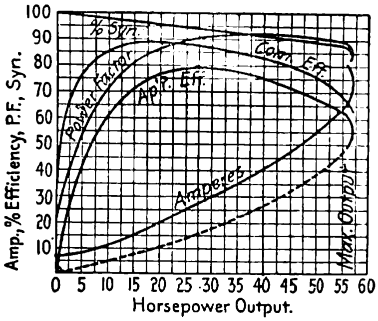


FIG. 61.—Typical performance curves of a 20-h.p., three-phase induction motor.

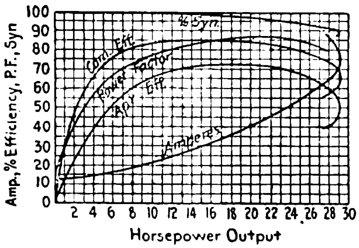


FIG. 62.—Performance curves of the motor shown in Fig. 63, when running single-phase.

is obtained and the starting torque is 440 lb. against 170 lb. without resistance. Curve *C* indicates the torque where too much resistance is used in the rotor. Curve *E* illustrates the torque single-phase, which is zero at starting. An induction motor starts as shown on curve *B* until it reaches the point *F*, when the resistance is cut out and the motor adjusts itself to its operating position at *G*. Thus, if the torque required of the motor for which the curve is shown,

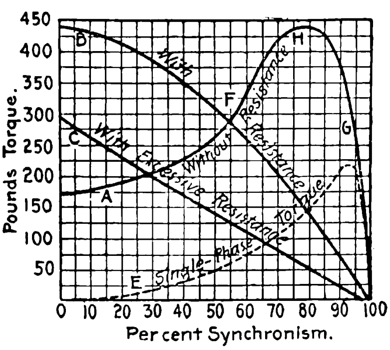


FIG. 63.—Torque curves of a 30-h.p. induction motor.

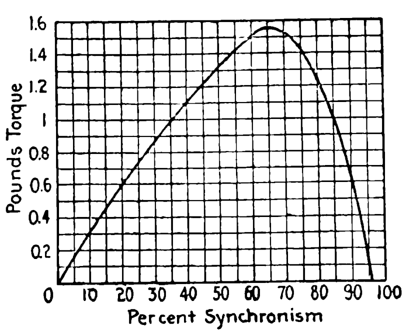


FIG. 64.—Torque curves of a 1-h.p., three-phase induction motor, running single phase.

is greater than 440 lb., shown at *H*, the motor will break down and come to rest. With the resistance in the rotor, a starting torque of 440 lb. is available, but this load cannot be brought up to normal speed. The motor can only bring the torque represented by the point *F*, in other words 290 lb., up to normal speed.

In Fig. 64 it will be noted that the torque of a three-phase motor running single-phase at starting is zero, rising to a maximum and reaching zero at synchronism. This means that an induction motor never runs at synchronous speed. The three-phase motor, Fig. 65, starts with a reasonable torque, reaches its maximum output and goes to zero again at synchronism.

Figs. 65 and 66 show the torque curves of squirrel cage motors without resistance in the rotor circuit. With resistance inserted in the armature, the torque is greater at starting and less later. This is the reason that it is advantageous to introduce resistance at starting and cut it out as synchronism is approached.

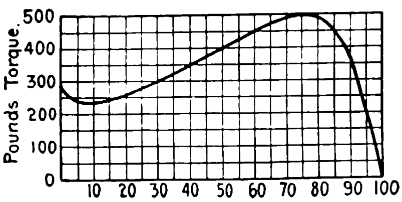


FIG. 65.—Torque curves of a 20-h.p., three-phase induction motor.

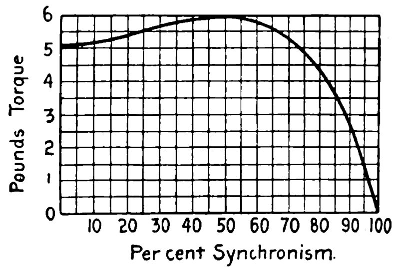


FIG. 66.—Torque curve of a 1-h.p., three-phase induction motor.

126. The Pull-out Torque of an Induction Motor.—All induction motors will "pull out" at some certain torque if they are overloaded. The "pull-out" limit—the maximum torque that can be developed—is that point at which further increase in torque will cause the motor speed to decrease rapidly and then to stop. This point is usually at between 2 and 4 times the full-load rated torque, depending on the design and the capacity of the motor. See the typical induction motor curve, Fig. 61.

127. Starting Torque and Starting Current of Alternating-current Motors (*F. D. Newbury, N.E.L.A. Convention Paper*, 1911). —In what follows the starting torque is expressed in terms of the full-load torque, and the starting current in terms of the full-load current. The smaller values given for synchronous motors cover the requirements of motor-generator sets and air compressors and pumps when the apparatus can be started without load. The larger values refer to motors for driving pumps and fans, which must be started under practically full-load conditions. The wide variation in the starting current comes from differences in construction of the motor or differences in the proportions of the motor, since, by increasing the size and cost of synchronous motors, the starting performances can be materially improved.

SINGLE-PHASE INDUCTION MOTORS, WITH CLUTCH, SPLIT-PHASE STARTER.—Starting torque, 1 to $1\frac{1}{4}$, starting current, $4\frac{1}{2}$ to 6.

SINGLE-PHASE INDUCTION MOTORS, WITHOUT CLUTCH, SPLIT-PHASE STARTER.—Starting torque, 2; starting current, $3\frac{1}{2}$ to $4\frac{1}{2}$.

POLYPHASE INDUCTION MOTORS, CAGE-WOUND TYPE, AUTO-TRANSFORMER STARTER.—Starting torque, 2; starting current, 7 to 8.

POLYPHASE INDUCTION MOTORS, WOUND-ROTOR TYPE, STEP-BY-STEP RESISTANCE STARTER.—Starting torque, 1; starting current, $1\frac{1}{4}$. Starting torque, 2; starting current, $2\frac{1}{2}$.

SYNCHRONOUS MOTORS, AUTO-TRANSFORMER STARTER.—Starting torque, 0.3 to 0.5; starting current, $1\frac{1}{2}$ to $2\frac{1}{2}$. Starting torque, 0.7 to 1; starting current, 4 to 8.

ROTARY CONVERTERS, AUTO-TRANSFORMER STARTER.—Starting torque, 0.2; starting current, $1\frac{1}{2}$. Starting torque, sufficient to start itself.

128. Speed Regulation of Induction Motors. Slip.—The speed regulation is the percentage drop in speed between no-load and full-load based on the maximum speed; it is usually called the "slip." The "slip" at full-load is usually about 5 to 7 per cent. At other loads it is approximately proportional to the load, therefore, at twice full-load the drop in speed will be approximately 10 to 15 per cent.

129. The slip of an induction motor is the ratio of the difference between the rotating magnetic-field speed (revolutions per minute or angular velocity) and the rotor speed to the rotating magnetic-field speed. The speed of the rotating magnetic field is equivalent to the synchronous speed of the machine (see table of synchronous speeds elsewhere in this section) which is determined by the frequency of the current and the number of poles of the machine. Then:

$$\text{Slip} = \frac{\text{Synchronous speed} - \text{Actual speed}}{\text{Synchronous speed}}$$

When there is no load on a motor the slip is very small, that is, the rotor speed is practically equal to the synchronous speed. Slip varies with the design of the motor and may vary from 4.0 to 8.5 per cent. at full-load in motors of from 1 to 75 h.p. of ordinary design.

Example.—What is the slip at full-load of a 4-pole, 60-cycle induction motor which has a full-load speed of 1,700 r.p.m.

Solution.—From Table 97 or Formula 94 the speed of the rotating field or the synchronous speed of a 4-pole, 60-cycle motor is 1,800 r.p.m. Then substituting in the above formula:

$$\text{Slip} = \frac{\text{Synchronous speed} - \text{Actual speed}}{\text{Synchronous speed}} = \frac{1{,}800 - 1{,}700}{1{,}800} = \frac{100}{1{,}800} = 5.5\%$$

Therefore the slip is 5.5 per cent. The voltage of the motor or whether it is single-phase, two-phase, or three-phase are not factors in the problem.

130. The Induction Motor Inherently a Constant-speed Motor. The Regenerative Feature.—A characteristic of the induction motor is that it tends to rotate at a definite synchronous speed irrespective of whether the motor is driving or being driven, providing there is no starting resistance in the rotor circuit. For instance, when a load is being lowered and the motor is connected to a source of energy, it acts as an alternating-current generator, the descending load furnishing the driving power. The motor delivers energy to the line. When load is being raised the motor absorbs energy from the line. This returning of energy to the line by a motor is termed regeneration. Consider an installation where cars loaded with ore are lowered down a slope on a railroad and the empty cars are hoisted back. The motor delivers about as much

power to the line when lowering as it consumes when hoisting, with the result that practically no energy is consumed in operating the system. The proof of this is that the watt-hour meter for such an installation runs backward about as much as it runs forward.

Another interesting example is a balanced passenger hoist wherein the passenger cars run over varying grades and sometimes one is loaded, at other times the other is loaded. The cars, when equipped with induction motors connected to a source of energy, run at a practically uniform speed without the use of brakes, whether the load overhauls the motor or not. This characteristic will not obtain if starting resistance is left in the rotor circuit, for then the motor will slow down in case it is delivering power to the cars and will operate at an over-speed if the cars are delivering power to the motor. (*Practical Engineer.*)

131. To Reverse the Direction of Rotation of a Polyphase Induction Motor.—For a two-phase, four-wire motor, interchange the connections of the two leads of either phase. For a two-phase, three-wire motor, interchange the two outside leads. For a three-phase motor, interchange the connections of any two motor leads.

132. A single-phase induction motor, when its rotor is not revolving, has no starting torque. After the rotor commences revolving there is a certain interaction of magnetic fields whereby there is exerted a continuous turning effort. While such a motor

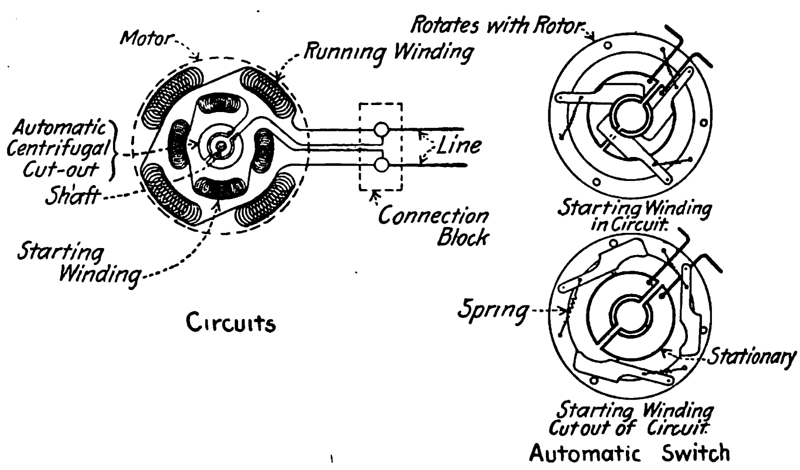


FIG. 67.—Single-phase motor diagram.

can be started by hand by giving the rotor a twist, the most common method of starting is by the so-called split-phase method. With this method the circuit supplying the motor is divided into two circuits and one is arranged in some way so as to have considerably more inductance than the other. Each circuit supplies a winding.

These windings are called the starting and running windings. The current in the starting winding differs in phase by practically 90 deg. from that in the running winding because of the excess

inductance in the starting circuit. The starting winding is arranged at practically 90 electrical degrees from the running winding. This latter winding in the motor shown in Fig. 67 consists of a greater number of turns of larger wire, well distributed over the stator, while the starting winding consists of fewer turns and of considerably smaller wire. In this motor the starting winding itself is designed so that it has more inductance than the running winding. In some motors, an inductance coil, carried in the base of the motor, is connected in series with the starting winding to provide the necessary inductance.

The running winding remains in the circuit at all times of motor operation, while the starting one only remains in circuit until the motor has reached synchronous speed or nearly so. When the speed is reached at which the starting winding should be cut out, an automatic centrifugal switch (see illustration) operates and opens the "starting" circuit and the motor continues to operate solely by virtue of the "running" winding and circuit.

133. **Phase Splitting and Repulsion Starting of Single-phase Induction Motors.**—In the former method two windings are used in the stator of the motor; one of these is the working winding, the other the starting winding (see 132). In some cases an external starting box is employed to secure the necessary phase difference in the current, in others the reactance is part of the secondary winding itself.

Where a single-phase induction motor is started by the "repulsion" method (see 135) the rotor is similar to the armature of a direct-current motor, being provided with form wound coils and a commutator. There are two sets of brushes, bearing on the commutator, these sets being short-circuited upon each other. The stator is supplied with single-phase current, and there is no electrical connection between the stator and the rotor. The currents in the stator set up a flux which reacts on the rotor, repelling the successive coils and thereby causing rotary motion. When the motor approaches synchronous speed a centrifugal device of some description short-circuits the commutator bars and lifts the brushes, transforming the motor into the induction type with practically a squirrel cage rotor.

134. **The Starting Torque, Starting Current and Speed Regulation of Single-phase Induction Motors.**—The single-phase induction motor, with phase-splitting starting device, is suitable for machines in which the starting torque is not over 150 per cent. of full-load torque. Almost invariably some type of clutch is used which allows the motor to attain nearly synchronous speed before picking up the load. The starting current with 150 per cent. of full-load torque is approximately 250 per cent. of full-load current, and the maximum torque is from 150 to 200 per cent. of the full-load torque. The speed regulation from no-load to full-load is good, being better than in the multiphase motor. In general, however, the efficiency, power factor and maximum torque are not as good as in corresponding multiphase motors. They are suited only for driving machinery where the starting torque required is light. The single-phase induction motor, with the

repulsion method of starting, has a starting torque of from 2 to 2½ times full-load torque, with 2 to 2½ times full-load current. (*A. B. Morrison*, *Power*, March 4, 1913.)

135. **The condenser-compensator method of starting single-phase induction motors** is shown in Fig. 68. Two terminals of the stator winding, which is practically of the standard three-phase construction, are connected to the supply mains. The third terminal of the stator winding is connected to the line through an auto-transformer. The main to which it is connected is determined by the direction of rotation desired. A condenser is also connected across the transformer to provide capacity. Then when the motor has reached synchronous speed the starting winding can be cut out by opening the switch and the motor then operates upon running winding only.

136. **The compensated repulsion single-phase motor** is one in which the line current passes through the stator and also through the rotor by means of two sets of brushes bearing on the commutator. There is also a second set of brushes set at an angle to the first which are short-circuited on themselves. This motor differs from the straight repulsion type in that it contains two additional sets of brushes and the stator and rotor are in electrical contact.

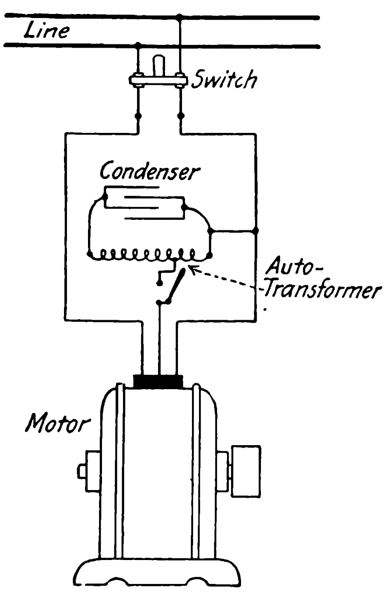


FIG. 68.—A single-phase, self-starting induction motor with a condenser starting arrangement.

137. **The compensated repulsion motor has a starting torque** of 2½ to 3 times full-load torque with approximately twice full-load current, and the maximum torque is from 3 to 3½ times full-load torque. The power factor is very high at all loads, but the efficiency is lower than in the induction motor. This type of motor is well adapted for loads where heavy starting torque is required with sudden overloads. It has the disadvantages of having a commutator and is somewhat more noisy than the induction motor after the latter is up to speed. (*A. B. Morrison, Jr.*, *Power*, March 4, 1913.)

138. **If a variable-speed single-phase motor is required,** some form of compensated repulsion motor is generally used. The behavior of the motor is very similar to that of the variable-speed wound-rotor multiphase-induction motor with resistance in series with the rotor. It is consequently, owing to its unstable speed characteristics, suited only to such applications as require a steady horse-power at given speeds. Its characteristics as regards starting torque, etc., are unchanged when used for variable speeds. The resistance is inserted in series with the brushes which are

normally short-circuited and the insertion of additional resistance decreases the speed. By the insertion of resistance in series with the brushes carrying the line current it is also possible to raise the speed of the motor slightly above synchronism.

139. Approximate Data on Single-phase Induction Motors, 110 to 440 Volts (*Electric Motors, Crocker and Arendt*).—The synchronous or no-load speed of any induction motor is determined by the number of its poles and the frequency. See **94.** Very small single-phase motors, such as fan motors, may not show performances as good as those tabulated below. Pull-out or "break-down" torque as tabulated is in terms of rated full-load torque.

Horse-power	No. of poles	Per cent. slip	Pull-out torque	Per cent. power factor at given loads				Per cent. efficiency at given loads				Synchronous speed at 60 cycles
				½	¾	Full	1¼	½	¾	Full	1¼	
½	4	6.0	1.5	46	58	66	68	53	60	63	60	1,800
1	4	4.0	1.6	55	59	73	75	60	63	68	62	1,800
2	4	2.5	1.8	56	65	77	76	71	75	78	77	1,800
5	4	2.5	1.8	78	83	86	86	71	76	77	76	1,800
10	4	2.5	1.8	75	81	84	83	75	79	80	79	1,800
20	6	2.0	1.9	78	80	86	87	85	88	86	85	1,200
30	8	2.0	1.9	68	80	85	84	77	81	83	82	900
50	4	2.3	2.0	91	94	93	91	82	84	86	86	1,800

140. Synchronous motors (*Carl D. Knight, Practical Engineer*, June 1, 1912).—Generally speaking, any modern alternating-current generator will operate with more or less satisfaction as a synchronous motor, and unless special operating features must be provided for, the two are often identical in construction.

There are two advantages of the synchronous motor, namely: it operates at a constant speed at all loads, provided the driving alternator runs at a constant speed, and its power factor is at all times under the control of the attendant; it can be used to correct low power factor of the system that feeds it in addition to driving a mechanical load, provided it has sufficient capacity.

The latter characteristic is often of considerable importance. It is well known that the power factor of the induction motor, even under full-load conditions, is seldom greater than 95 per cent., and it often falls as low as 50 or 60 per cent. at light load. The result is that an alternating-current generator driving a considerable number of induction motors ordinarily operates at a comparatively low power factor. If this alternator is loaded to its full kilowatt capacity at such a low power factor, overheating will result.

If the alternator is not loaded beyond its normal current capacity it operates at a low energy load but with the same heating losses as at full-load, on account of the reduced power factor. The advantage of the synchronous motor on such a system is, that by proper adjustment of its field current it may be made to draw from the line a current which is leading with respect to the voltage,

and which will neutralize the lagging current taken by the induction motors. The current in the alternating-current generator can thereby be brought into phase with the voltage and the generator will operate under its normal conditions. When used in this manner as a compensator for lagging current, the synchronous motor must be of larger size than required by its power output, on account of the excess current which it draws from the line.

141. **A synchronous condenser** is a synchronous motor that operates to correct power factor only and does not pull any mechanical load.

142. **Disadvantages of the Synchronous Motor.**—To offset its advantages, the synchronous motor has disadvantages which ordinarily limit its application to relatively large capacities, and to installations where it can be used as a compensator for lagging current. The chief disadvantage is that the motor has small starting torque even at full-load current. The motor also requires a supply of direct current for its field excitation.

143. **The Uses of Synchronous Motors** (*Standard Handbook*).—Due to the fact that synchronous motors require more care than induction motors, are not self-exciting and are started with some difficulty, synchronous motors are seldom employed where induction motors can be used. Where an induction motor would be objectionable on account of the large lagging wattless currents which affect the voltage regulation, a synchronous motor may be used to advantage. It is also used as a "synchronous condenser" in connection with induction motor loads for power factor correction as noted above.

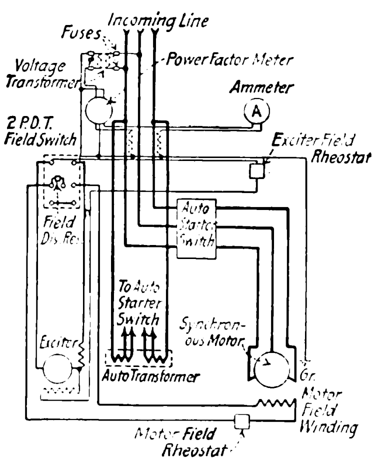


FIG. 69.—Connections for a self-starting synchronous motor.

144. **The steps in starting a synchronous motor** are about as follows:

(1) See that motor is clean, that bearings are well supplied with oil, and that oil rings are free to turn.

(2) See that all switches are open.

(3) Close the double-throw field switch, cutting in the field rheostat with its resistance all in.

(4) Close the main-line switch (if any) in the circuit and throw in the double-throw switch, throwing it in the starting position. The motor should start and speed up to synchronism in from 30 to 60 sec.

(5) When motor is up to speed, throw field switch over to the other (running) position with rheostat all in.

(6) Throw double-throw main switch over to running position, putting motor on full line voltage.

(7) Adjust field rheostat for minimum armature current.

Fig. 69 shows the method of connecting a three-phase, self-starting synchronous motor to its exciter. This diagram shows

a double-throw switch in the field circuit. This switch, however, may (where the exciter is connected to the same shaft as the synchronous motor) be single-throw and the field connected direct through the exciter armature with the rheostat in the circuit. The field is thus short-circuited at standstill and is gradually charged as the motor speeds up.

145. **Starting Synchronous Motors.**—Practically any polyphase synchronous motor may be started by applying full-load voltage to the armature, leaving the field open until the motor has reached its normal speed. Such a procedure would require, however, 2 or more times the full-load current of the machine. Since the power taken by a synchronous motor starting in this manner is of very low power factor, the line disturbances might be considerable. Starting at full line voltage is also liable to induce in the field windings an excessively high voltage, often resulting in breaking down the insulation.

To limit the starting current to a reasonable value, auto starters or compensators are often used. These are similar and used in exactly the same manner as the starting compensators used with induction motors. When starting with a compensator the field-winding circuit is opened by a switch provided for the purpose or the field circuit may be closed through a resistance until the motor has attained its normal speed.

This arrangement does not provide a great starting torque, and in most modern synchronous motors the revolving field of the motor is provided with a special auxiliary winding similar to the winding on the rotor of a squirrel cage induction motor. It has been possible to construct motors having nearly 30 per cent. of full-load torque at approximately $1\frac{1}{2}$ times full-load current. Beside improving the starting torque this squirrel cage winding also has a tendency to reduce the hunting or pumping effect which is sometimes encountered in the operation of synchronous motors.

Where the motor to be started is comparable with the size of the generator which drives it, it is often necessary to connect a small induction motor to the synchronous motor to bring it up to speed. When approximately normal speed has been reached the synchronous motor is thrown on the line as before, and the field closed immediately.

When a large starting torque is required, as, for example, in driving a considerable amount of shafting, it is often impractical to start the load and the motor from rest simultaneously. In such instances it is customary to install a friction clutch or similar device between the motor and its load, so that the motor may attain its normal speed before any load is imposed upon it.

Occasional installations are encountered where the motor is the only load on the driving generator. In such cases it is possible to connect the synchronous motor to the line before starting the alternator. On starting the alternator, both will come up to speed together.

Cases have been known in which the motor was a small part of the load on the driving alternator, that is, the alternator was larger compared with the motor, when an auto starter was used

to raise the voltage at start instead of to reduce it. This method gives a fairly good torque, but requires large current, and the operator must be certain that the motor windings will not be damaged before trying such a method.

In cases where it is desired to use an alternating-current generator as a motor and no compensator is available, water rheostats can be used to good advantage, one being placed in series with each phase. They are short-circuited when the motor has attained normal speed. (*Practical Engineer.*)

TROUBLES OF ALTERNATING-CURRENT MOTORS AND GENERATORS, THEIR LOCALIZATION AND CORRECTION

146. Troubles of Alternating-current Machinery.—Much of the material under this heading is based on that in the book *Motor Troubles*, by E. B. Raymond. For further data relating to alternating-current-machinery troubles and their correction see the author's ELECTRICAL MACHINERY, published by the McGraw-Hill Book Company.

147. Induction Motor Troubles (*H. M. Nichols, Power and the Engineer*).—The author asserts that the unsatisfactory operation of an induction motor may be due to either external or internal conditions. The voltage or the frequency may be wrong, or there may be an overload on the machine. Low voltage is the most frequent cause of trouble. The starting current sometimes amounts to twice the running current, with the result that the voltage is particularly low at starting. The best remedy for this disorder is larger transformers and larger motor leads, one or both. The troubles that occur most frequently within the motor itself are caused by faulty insulation, and by uneven air gap due to the springing of the motor shaft or to excessive wear in the bearings. If a wound-rotor machine refuses to start, the trouble may be due to an open circuit in the rotor winding. A short-circuited coil in the motor will make its existence known by local heating in the latter. Most motors designed to employ a starting resistance will not start at all if the resistance be left out of the secondary circuit.

148. Troubles of Alternating-current Generators (*Westinghouse Instruction Book*).—The following causes may prevent alternating-current generators from developing their normal e.m.f.:

The speed of the generator may be below normal.

The switchboard instruments may be incorrect and the voltage may be higher than that indicated, or the current may be greater than is shown by the readings.

The voltage of the exciter may be low because its speed is below normal, or its series field reversed, or part of its shunt field reversed or short-circuited.

The brushes of the exciter may be incorrectly set.

A part of the field rheostat or other unnecessary resistance may be in the field circuit.

The power factor of the load may be abnormally low.

149. Causes of Shutdowns of Induction Motors.—Sometimes there is trouble from blowing fuses. Or possibly, and more serious, the fuses do not blow and the motor, perhaps humming loudly, comes to a standstill. Under these conditions, the current may be 10 times normal, so that the heating effect, being increased as the square of the current or 100 fold, causes the machine to burn out its insulation.

Since the torque or turning power of an induction motor is proportional to the square of the applied voltage (one-half voltage produces only one-quarter torque), it is evident that lowering the voltage has a decided effect upon the ability of the motor to carry load, and may be the cause of its stopping. Another cause may be that the load on the motor is more than equal to its maximum output.

The bearings may have become worn, so that the air-gap (which ordinarily is not much over 0.040 in. and on small motors as small as 0.015 in.) has been gradually reduced at the lower side of the rotor to practically zero. The rotor commences to rub on the stator. The friction soon becomes so great that it is more than the motor can carry. The result is that it shuts down.

A shut-down may be due to bearings introducing excessive friction. Hot bearings, in turn, may be due to excess of belt tension, dirt in the oil, oil rings not turning, or to improper alignment of the motor to the machine that it drives. Hence, under such conditions, it should be ascertained whether the voltage has been normal, whether the air-gap is such that the armature is free from the field, and whether the load imposed upon the motor is more than that for which it was designed. In any installation a system should be arranged whereby an inspector will examine the gap, bearings, etc., periodically.

Rarely, shutting down may be due to the working out of the starting switch, which may be located within the armature. Such a switch is operated by a lever engaging a collar which bears on contacts which, as they move inward, cut out the resistance in series with the rotor winding and located within it.

If the short-circuiting brushes work back, introducing resistance into the armature circuit while the machine is trying to carry load, it will at once slow down in speed and probably stop, usually burning out the starting resistance. Of course, this can occur only from faulty construction. The remedy is to fit the brushes properly, so that they will not work out. It is well to inspect them at the time of air-gap inspection.

150. Low Torque while Starting Induction Motors.—Although the circuit to the motor be closed, sometimes it does not start. The same general laws of voltage, etc., apply to the motor at starting as when running. Hence, the points mentioned under "Shut-downs" should be investigated and if necessary corrected. The resistance, which is frequently inserted in the armature, may be short-circuited, thus giving a low starting torque. Unless a starting compensator is used for starting, it is necessary, in order to obtain a proper starting torque with a reasonable current, that a resistance be inserted in the rotor circuit. The resistance not

only limits the current, which would, with the motor standing still, be large, but it causes the current of the armature to assume a more effective phase relation, so that with the same current a far larger torque is obtained. A partial or complete short-circuit of the resistance partially or wholly ruins the starting torque.

151. Low Maximum Output of Induction Motors.—The maximum load which a motor can carry may be less than desired, or less than the name plate indicates. If the voltage, air-gap, load, etc., are right, it may be possible that a mistake has been made in connections. It is then easiest to return the motor to the factory, but if immediate operation is essential, the armature connections can easily be changed so as to give a large increase in output. To ascertain what to do, remove the bracket on the side of the motor which covers the connections between the coils. Each motor has a certain number of poles. Pick out one phase, and find out how many groups of coils are connected up. From this, the number of poles can be determined. A better way is to calculate this from the speed of the motor and the frequency of the circuit on which it is running. See 94.

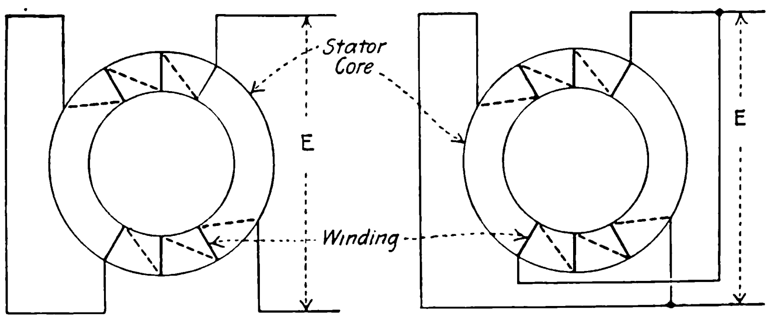


FIG. 70.—Connections of induction-motor coils.

From an examination of the connections it can be easily determined whether the poles in any place are connected in series or in multiple, or in series-multiple. Thus, in a motor, the connections may be as shown in Fig. 70, *I*, which shows the windings of one phase of a four-pole motor. If the connections be changed to those in Fig. 70, *II*, each coil will then receive double its former voltage and the motor will give four times the output. Before making a change in connections such as that indicated here one must ascertain to a certainty that the increased current that will result will not injure the windings.

It should be borne in mind, however, that this makes the motor less efficient, increasing the exciting current, and thus lowering the power factor. If conditions demand it, this method may be followed. The temperature under the new conditions should be carefully watched to see that there is not undue heating. The only change in connections that can be used for quarter-phase motors is of the type of the one just described.

With three-phase motors the poles can be grouped not only as

previously suggested, but a variation of connections from delta to star, or the reverse, can be made. A delta-connected, two-pole motor is shown in Fig. 71, *I*, where the three phases are indicated by the letters, *A*, *B* and *C*. Any one of these phases may have poles connected in either series or multiple. In a delta connection with the coils spaced 120 deg. apart, as shown in Fig. 71, *I*, each phase has the line voltage *E*.

In the star connection the phases are joined as in Fig. 71, *II*. In this case, as in Fig. 71, *I*, each phase may have poles in series or in multiple. In the case of Fig. 71, *II*, each coil has a voltage of $0.58 \times E$.

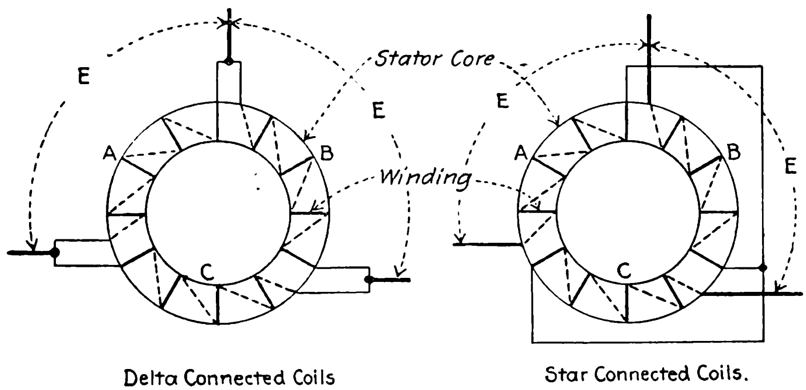


FIG. 71.—Three-phase motor coil connections.

152. Winding Faults of Induction Motors.—When a new induction motor is received, it sometimes happens that in attempting to operate the machine, although it will start, the currents are excessive and unbalanced, undue heating appears or a peculiar noise is emitted and accompanied possibly by dimming of the lights on the same circuit and the lowering of speed with perhaps actual shut-down of other induction motors thereon. If, after examination, there is found to be no difficulty with the air gap, belt tension, starting resistance or bearings, the probabilities are that the coils of the motor have been wrongly connected or that the winding has been damaged during transportation. Certain indications of these conditions are shown by instrument readings. The winding faults in a three-phase motor may be:

1. One coil of the rotor may be open-circuited. The armature or rotor may have a defective winding just as may the field. A coil-wound rotor construction is used only when a starting resistance is used. When a compensator is used no starting resistance is required, and the winding consists simply of bars connected at the ends by a ring.
2. Two coils or phases of the armature may be open-circuited.
3. Armature may be connected properly but field coil or phase may be reversed.
4. Part of field may be short-circuited.
5. One phase of field may be open-circuited.

The symptoms shown for certain of these trouble conditions are indicated in the following data from actual tests on a 5-h.p., six-pole, 1,200 r.p.m., 60-cycle induction motor.

153. **With an open circuit in field or stator** in a three-phase motor, current would flow only in two legs. There would be no current in the other leg and the motor would not start from rest with all switches closed. However, a three-phase motor or a two-phase motor will run and do work single-phase if it is assisted in starting. The starting torque is zero, but as the speed increased the torque increases.

With a small motor, giving a pull on the belt will introduce enough torque so that it will pick up its load. Therefore while an open circuit in the field winding should be found and repaired, if there is not time for repairs, the motor can be operated single-phase to about two-thirds of normal load. The power factor conditions and effects on the rest of the circuit are practically no worse than when the motor is running three-phase. The torque of a 1-h.p., three-phase induction motor from rest to synchronism, when running single-phase, is indicated in Fig. 64. The torque curve of a 20-h.p., three-phase motor is given in Fig. 65, and of a 1-h.p., three-phase motor in Fig. 66.

154. **Balking of Induction Motors.**—With induction motors having certain slot relations between armature and field, at one certain percentage of speed, the torque will go almost to zero. The motor will start its load properly, but will suddenly lose its torque at some slow speed, perhaps one-tenth normal. Such trouble may be caused by a magnetic locking effect of the teeth of the armature with the poles of the field. This phenomenon, with ordinary measuring instruments and facilities cannot easily be measured. But with special torque measuring instruments the peculiar synchronous locking can be measured and exactly located. If all other investigations show no cause of weak torque during the rise of the speed from rest to synchronism, the relation between the number of poles and slots in the rotor may account for the trouble. This is an unusual condition, but on squirrel cage motors it has existed. There is no remedy but a change in design, so that the manufacturer must take action for correction.

155. **Squirrel Cage Armature or Rotor Troubles.**—Unusual operation due to reversals of phase, phases open-circuited, and other causes, occur with squirrel-cage armatures as well as with wound armatures. Poor soldering of the armature bars may be the cause. Sometimes a solder flux may be used that will insure proper operation for a while, but time will develop poor electrical contacts due to chemical action at the joints. If the resistances of all of the squirrel cage joints are uniformly high, the effect is simply like that of an armature having a high resistance, which causes a lowering of the speed and local heating at the joints. If some of the joints are perfect, but some bad, the motor may not have the ability to come up to speed and there will be unbalanced currents.

156. **Effects of Unbalanced Voltages on Induction Motors.**—The maximum output of a polyphase induction motor may be

materially decreased if the voltages impressed on the different phases are unequal. On a three-phase system, the three voltages between the legs 1–2, 2–3 and 1–3 should be approximately equal. Also on a two-phase the voltage 1–2 should equal 3–4. If these voltages, impressed on the induction motor, are not equal the maximum output of the motor as well as the current in the various legs is proportionately affected.

For example, with a two-phase motor, if the voltages in the two legs differ by 20 per cent., a condition sometimes met in normal practice, the output of the motor may be reduced 25 per cent. Then, instead of being able to give its maximum output of, say, 150 per cent. for a few moments, it will give but 112 per cent. The varying loads which the motor may have to carry may shut it down. In cases of low maximum output, the relative voltages on the various legs should always be investigated. If they vary, the trouble may be due to this variation.

In addition to the effect on the maximum output, the unequal distribution of current in a two-phase motor under such conditions may be quite serious. Consider a specific case of a 15-h.p., six-pole, 1,200-r.p.m., 220-volt motor, with the voltage on one leg 220 and the voltage on the other leg 180; current in leg No. 1 was 60 amp. and in leg No. 2 35 amp. at full-load. The normal current at full-load was 35 amp. Thus the fuse might blow in the phase carrying the high current, causing the motor to run single-phase. If an attempt is made to start the motor the blown fuse not being noticed, there would be no starting torque.

Consider the specific case of a six-pole, 10-h.p., 1,200-r.p.m., 160-volt, three-phase motor. The motor on normal voltage, at full-load, took 110 amp. in each leg. With unbalanced voltages of 161, 196 and 168, only full-load could be carried, although the average of these voltages is such that it might be assumed that 25 per cent. overload should be carried.

157. Induction Motor Starting Compensator Troubles.—Sometimes a mistake is made in the connections to the compensator, so that full voltage is used at starting and the lesser voltage after throwing over the switch. Then the motor at starting takes excessive current, and, since the maximum output is in proportion to the square of the voltage, the motor capacity is much reduced when it is apparently running on the operating position. Such action, therefore, can usually be accounted for by a wrong connection in the compensator. Sometimes a motor connected to a compensator takes more current at starting than it should, under which conditions a lower tap should be tried. Compensators are usually supplied with various taps and the one should be selected which produces the least disturbance on the line, giving at the same time the desired starting torque on the motor.

When a motor, having been connected to a compensator, will not start, the cause may be entirely in the compensator. The compensator may have become open-circuited, due to a flash within. The switch may have become deranged, so that it will not close, or a connection within the compensator may have become loosened. Possibly, when a motor will not start when

connected to a compensator just installed, a secondary coil may be "bucked" against another secondary coil within the compensator so that no voltage is produced by the compensator at the motor. This results in no particular heating and in no apparent phenomenon which would account for the motor not starting. An ammeter in the motor leads will indicate the absence of current, or a voltmeter will indicate the absence of voltage.

158. **Induction Motor Collector Ring Troubles.**—It is essential that the contact of the brushes on the collector rings be good, else the contact resistance will be so great as to slow the motor down and to cause heating of the collector itself. This effect is particularly noticeable when carbon brushes are used. The contact resistance of a carbon brush under normal operation pressure and carrying its usual density of current (40 amp. per square inch) is 0.04 ohm per square inch. Thus, under normal conditions, the drop is 0.04×40, which equals 1.6 volts. If the contact is only one-quarter the surface, this drop would be 6.4 volts, and might materially affect the speed of the motor. Thus, if the speed is below synchronous speed more than it should be (normally it should not be over 4 per cent. below), an investigation of the fit of the brush upon the collector may show up the trouble.

If copper brushes are used, this trouble is much less liable to occur, since the drop of voltage, due to contact resistance when running at normal density (150 amp. per square inch), is only one-tenth that of carbon. The same trouble may occur due to the pigtail, which is usually used with carbon brushes, making poor contact with the carbon, which gives the same effect as a poor contact with the collector itself.

159. **Hunting of Induction Motors.**—In very rare cases an induction motor will hunt and cause much trouble. The phenomenon appears as a speed variation of 1 or 2 per cent. each side of the normal speed, with a period of vibration depending upon the conditions. It may be anywhere from 10 to 500 swings a minute.

This rare phenomenon of induction motors depends upon the drop in the line between the generator operating the induction motor and the motor itself, and upon the design and slot relations of field and armature. It will cease if the line resistance be cut out between the motor and the generator. If this is not possible, it can sometimes be stopped on a three-phase motor by changing from delta- to Y-connection, or possibly the grouping of the poles may be changed. In any case, the flux in the motor is altered.

The period of hunting has nothing whatever to do with the hunting of the generator. Hunting of a motor may occur even though the generator speed is exactly uniform. This action is entirely distinct from a variation of the uniformity of the speed of the generator due to the engine driving, which lack of uniformity is repeated by the motor itself. It is more vicious and usually results in a gradual increase of amplitude of swing until the motor finally gets swinging so badly that it finally breaks down and stops entirely. Ordinarily, the manufacturer is responsible, but a change of connections will often cure the trouble and keep the apparatus in operation until a permanent correction can be effected.

160. Improper End Play in Induction Motors.—Induction motors are so designed that the revolving parts will play endwise in the bearing; $\frac{1}{16}$ in. or so. If in setting up the machine the bearings so limit this end action that the rotor does not lie exactly in the middle of the stator, there is a strong magnetic pull tending to center the rotor. If the bearings will not permit this centering, the thrust collars must take the extra thrust which, in an induction motor, is considerable. If in addition to the magnetic thrust the belt pull is such as to also draw in the same direction, the trouble is increased. The end force may be such as to heat the bearing excessively and to cause cutting, soon rendering the motor inoperative.

In case of trouble with bearings, the end play should be tested by pushing against the shaft with a small piece of wood, placed on the shaft center. With the machine operating under normal conditions there should be no particular difficulty in pushing the shaft first one way from one side, and then the other way from the other side. If it is found that the revolving part is hugging closely against one side, the trouble can be corrected either by pressing the spider along the shaft in a direction toward which the hugging is occurring, or by driving the tops of the lamination teeth in the same direction. With a wooden wedge, the tops of the teeth can often be without any difficulty driven over $\frac{1}{8}$ to $\frac{3}{16}$ in. This movement will usually correct the trouble. Driving the teeth of the stator $\frac{1}{8}$ in. or so in the opposite direction to that of the end thrust will usually accomplish the same result. It is best to choose the teeth (stator or rotor) which are most easily driven over. The thin long ones move easier than do the short broad ones.

161. Oil Leakage of Induction Motors.—Sometimes a bearing will permit oil to be drawn out, perhaps a very little at a time. Ultimately enough will accumulate to show on the outside or on the windings of the machine. While a motor will run for a period with its windings wet with ordinary lubricating oil without being apparently injured, insulation soaked with oil will deteriorate and eventually fail.

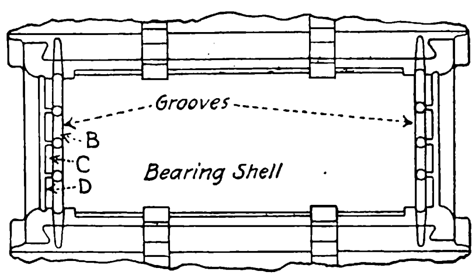


Fig. 72.—Grooves to prevent oil leakage.

One of the principal causes is a suction of the oil due to the drafts of air from the rotor, and one of the best methods of stopping the trouble, under ordinary conditions, is to cut grooves as shown in Fig. 72 at *B* and *D*. These grooves on a 50-h.p. motor may be $\frac{1}{8}$ in. deep and $\frac{3}{16}$ in. wide. Each groove has three holes drilled through the bearing shell to convey the oil collected by the grooves into the oil well. These grooves are just as effective with a split as with a solid bearing. It is impossible here to go into the various causes of oil leakage. The grooves as suggested are a general remedy and cover many cases.

162. General Summary of Synchronous-Motor Troubles.—Failure of a synchronous motor to start is often due to faulty connections in the auxiliary apparatus. These should be carefully inspected for open circuits or poor connections. An open circuit in one phase of the motor itself, or a short-circuit will prevent the motor from starting. Most synchronous motors are provided with an ammeter in each phase, so that the last two causes can be determined from their indications—no current in one phase in case of an open circuit, and excessive current in case of a short-circuit. Either condition will usually be accompanied by a decided buzzing noise, and in case of a short-circuited coil, it will often be quickly burned out. The effect of a short-circuit is sometimes caused by two grounds on the machine.

Starting troubles should never be assumed until a trial has been made to start the motor light, that is, with no load except its own friction. It may be that the starting load is too great for the motor.

If the motor starts but fails to develop sufficient torque to carry its load when the field circuit has been closed, the trouble will usually be found in the field circuit. First, determine whether or not the exciter is giving its normal voltage. Assuming the exciter voltage to be correct, the trouble will probably be due to one of the following causes. (1) Open circuit in the field winding or rheostat or (2) short-circuit or reversal of one or more of the field spools. Open circuit can often be located by inspection or by use of the magneto.

The majority of field troubles are caused by excessive induced voltage at start, or by the field circuit being broken. This excessive voltage may break down the insulation between field winding and frame or between turns on any one field spool, thus short-circuiting one or more turns, or it may even burn the field conductor off, causing an open circuit.

Causes of overheating in synchronous motors are about the same as those in alternating-current generators. Probably the most common cause of overheating is excessive armature current due to an attempt to make the motor carry its rated load, and at the same time compensate for a power factor lower than that for which it was designed. If the motor is not correcting low power factor, but doing mechanical work only, the field current should be adjusted so that the armature field is a minimum for the average load that the motor carries.

163. Difficulties in Starting Synchronous Motors.—A synchronous motor is weaker in starting than is an induction motor. In general, however, a synchronous motor will start itself and perhaps a very light load. Starting requires no field current as the flux which tends to start the motor is not the flux that operates it when it is up to speed. In starting, the field current is lagging, and a lagging current tends to pull down the voltage on the supply circuit, hence tends to lower the applied voltage. The starting torque, as in an induction motor, is proportional to the square of the applied voltage. For example, if the voltage is halved, the starting effort is quartered. When a synchronous motor will not

start, it may be because the voltage on the line has been pulled down below the value necessary for starting.

In general, at least half voltage is required to start a synchronous motor. Difficulty in starting may also be caused by an open circuit in one of the lines to the motor. Assume the motor to be three-phase. If one of the lines is open the motor becomes single-phase, and no single-phase synchronous motor, as such, is self starting. The motor will, therefore, not start, and will soon get hot. The same condition is true of a two-phase motor, if one of the phases is open-circuited.

Difficulty in starting may be due to a rather slight increase in static friction. It may be that the bearings are too tight, perhaps from cutting during the previous run. Excessive belt tension, in case the synchronous motor is belted to its load, or any cause which increases starting friction will probably give trouble. Difficulty in starting may be due to field excitation being on the motor. After excitation exceeds one-quarter normal value, the starting torque is influenced. With full field on, most synchronous motors will not start at all. If the proper voltage is applied to a motor, and the circuits are all closed except the field circuit and the friction is a minimum, and still the motor will not start, the fault is probably with the manufacturer. Pole pieces often receive extra starting windings or conducting bridges are provided between the pole pieces to assist in starting. Possibly the manufacturer in shipping may have omitted these devices. In such cases one must refer to the factory.

Usually compensators are used for starting synchronous motors. If there is a reversed phase in a compensator, or, if the windings of the armature of the synchronous motor are connected incorrectly, there will be little starting torque. Incorrect connection can be located by noting the unbalanced entering currents. Readings to determine this unbalancing should be taken with the armature revolving slowly. The revolving can be effected by any mechanical means. While the motor is standing still, even with correct connections, the armature currents of the three phases usually differ somewhat. This is due to the position of the poles in relation to the armature, but when revolving slowly, the currents should average up. If the rotor cannot be revolved mechanically, similar points on each phase of the armature must be found. Then when the rotor is set successively at these points the currents at each setting should be the same. Each phase when located in a certain specific position as related to a pole, should, with right connections, take a certain specific current. With wrong connections, the currents will not be the same.

164. Open Circuit in the Field of a Synchronous Motor.—If in the operation of a synchronous motor the field current breaks for any reason, the armature current will largely increase, causing either a shut-down or excessive heat. It becomes important, therefore, in synchronous motors to have the field circuit permanently established.

165. Short-circuit in an Armature Coil of a Synchronous Motor.—A short-circuit in an armature coil of a synchronous motor

burns it out completely, charring it down to the bare copper. When this occurs, the symptoms are so evident that there is no difficulty in identifying the trouble. Such a coil may under ordinary circumstances be cut out and operation continued. In an induction motor, the current in the short-circuited coil rises only to a certain value, but heats it many times more than normal. It is not necessarily burned out immediately, and perhaps it may not be burned out at all.

166. Hunting of Synchronous Motors.—Synchronous motors, served by certain primary sources of energy, tend to "hunt." The periodicity of the swinging is determined by properties of the armature and the circuit. It may reach a certain magnitude and there stick, or the swinging may increase until finally the motor breaks down altogether. This trouble usually occurs on long lines having considerable resistance between the source of energy and the synchronous motor. Sometimes it occurs under the most favorable conditions. Irregular rotation of a prime mover, such as a single-cylinder steam engine, is often responsible for the trouble. The usual remedy is to apply to the poles, bridges of copper or brass in which currents are induced by the wavering of the armature. These currents tend to stop the motion. Different companies use different forms of bridges. When hunting or pulsating occurs, and the motor is not already equipped with bridges, it is best to consult the manufacturer. In general, the weaker the field on a synchronous motor, the less the pulsation. Sometimes pulsation may be so reduced that no trouble results by simply running with a somewhat weaker field current.

167. Improper Armature Connections in Synchronous Motors.—This trouble usually manifests itself by unbalanced entering currents and by a negligible or very low starting torque. The circuits should be traced out and the connections remade until the three entering currents for three-phase, or the two entering currents for two-phase, are approximately equal. These currents will not be equal even with correct connection when the armature is standing still.

168. Polarity of Synchronous Motors.—Since the winding of a synchronous motor armature is in series all the way around the circumference and under all of the poles, except in exceedingly rare cases, the trouble from a reversed pole is much less serious than with an induction motor or direct-current machine. With a reversed pole everything operates fairly well. The only trouble is that the fields require more current than they should because of the pole that is opposing the field. If, therefore, excessive field current is required for minimum input to a motor, it is a good plan to test the polarity of all the spools with a compass.

169. Bearing troubles of synchronous motors are similar to those of induction motors. A difference is that, with a synchronous motor, the air-gap between the revolving element and the poles is relatively large, so that the wearing of the bearing, which throws the armature out of center, is not so serious as with an induction motor. End play should be treated the same as with an induction motor.

170. **Bearing Troubles of Motors and Generators.**—Modern generators and motors have self-oiling bearings. They should be filled to such a height that the rings will carry sufficient oil upon the shaft. If the bearings are too full, oil will be thrown out along the shaft. Watch the bearings carefully from the time the machine is first started until the bearings are warmed up, then note the oil level. The expansion of the oil due to heat and foaming raises the level considerably during that time. The oil should be renewed about once in six months, or oftener if it becomes dirty or causes the bearings to heat.

The bearings must be kept clean and free from dirt. They should be examined frequently to see that the oil supply is properly maintained and that the oil rings do not stick. Use only the best quality of oil. New oil should be run through a strainer if it appears to contain any foreign substances. If the oil is used a second time it should first be filtered and, if warm, allowed to cool. If a bearing becomes hot, first feed heavy lubricant copiously, loosen the nuts on the bearing cap, and then, if the machine is belt connected, slacken the belt. If no relief is afforded by these means, shut down, keeping the machine running slowly until the shaft is cool, in order that the bearing may not "freeze." Renew the oil supply before starting again. A new machine should always be run at a slow speed for an hour or so in order to see that it operates properly. The bearings should be inspected at regular intervals to insure that they always remain in good condition. The higher the speed, the more care should be taken in this regard.

A warm bearing or "hot box" is probably due to one of the following causes: (1) Excessive belt tension. (2) Failure of the oil rings to revolve with the shaft. (3) Rough bearing surface. (4) Improper lining up of bearings or fitting of the journal boxes.

STARTING AND CONTROLLING DEVICES FOR MOTORS

171. **The National Code rules require that each motor** and its starter be protected by fuses or a circuit-breaker and controlled by a switch which must plainly indicate whether on or off. The switch and cut-out (fuses or circuit-breaker) are preferably located near the motor and in plain sight of it. All wiring should be neat and workmanlike and the wires should be run in conduit wherever possible.

172. **Speed Control of Direct-current Electric Motors. Rheostats** (*The Electric Controller & Mfg. Company*).—A direct-current motor of any capacity, when its armature is at rest, offers a very low resistance to the flow of current and an excessive and perhaps destructive current would flow through it if it were connected directly across the supply mains while at rest. Consider a motor adapted to a normal full-load current of 100 amp. and having a resistance of 0.25 ohm; if this motor were connected across a 250-volt circuit a current of 1,000 amp. would flow through its armature—in other words, it would be overloaded 900 per cent. with consequent danger to its windings and also to the driven machine.

In the case of the same motor, with a rheostat having a resistance of 2.25 ohms inserted in the motor circuit, at the time of starting the total resistance to the flow of current would be the resistance of the motor (0.25 ohm) plus the resistance of the rheostat (2.25 ohms), or a total of 2.5 ohms. Under these conditions exactly full-load current, or 100 amp., would flow through the motor, and neither the motor nor the driven machine would be overstrained in starting. This indicates the necessity of a rheostat for limiting the flow of current in starting the motor from rest.

An electric motor is simply an inverted generator or dynamo, consequently when its armature begins to revolve a voltage is generated within its windings just as a voltage is generated in the windings of a generator when driven by a prime-mover. This voltage generated within the moving armature of a motor opposes the voltage of the circuit from which the motor is supplied, and hence is known as a "counter-electromotive force." The net voltage tending to force current through the armature of a motor when the motor is running is, therefore, the line voltage minus the counter-electromotive force.

In the case of the motor above cited, when the armature reaches such a speed that a voltage of 125 is generated within its windings, the effective voltage will be 250 minus 125, or 125 volts, and, therefore, the resistance of the rheostat may be reduced to 1 ohm without the full-load current of the motor being exceeded. As the armature further increases its speed, the resistance of the rheostat may be further reduced until, when the motor has almost reached full speed, all of the rheostat may be cut out, and the counter-electromotive force generated by the motor will almost equal the voltage supplied by the line so that an excessive current cannot flow through the armature.

In practice, a rheostat is provided for starting a direct-current electric motor. The conductor providing the resistance is divided into sections and is so arranged that the entire length or maximum resistance of the rheostat is in circuit with the motor at the instant of starting and that the effective length of the conductor, and hence its resistance, may be reduced as the motor comes up to speed.

In cutting out the resistance of a starting rheostat care must be used not to cut it out too rapidly. If the resistance is cut out more rapidly than the armature can speed up, a sufficient counter-electromotive force will not be generated to properly oppose the flow of current, and the motor will be overloaded.

173. **Rheostatic Controller.**—If all the resistance of the starting rheostat (see above paragraph) is not cut out, the motor will operate at reduced voltage, and hence at less than normal speed. A rheostat so arranged that all or a portion of its resistance may be left in a motor circuit to secure reduced speeds is called a "rheostatic controller." Such rheostatic controllers are used for controlling series and compound-wound motors driving cranes and similar machinery requiring variable speed under the control of an operator.

174. **In a series-wound motor the speed varies inversely as the load**—the lighter the load the higher the speed. A series-wound

motor of any size, when supplied with full voltage under no-load, or a very light load, will "run away" just as will a steam engine without a governor when given an open throttle.

For a given load, a series-wound motor with its rheostat in series draws the same current irrespective of the speed and for a given load the speed varies directly as the voltage. The speed at a given load may be varied by varying the resistance in the motor circuit; in the meantime if the load on the motor be constant the current drawn from the line will be constant regardless of the speed.

175. **Shunting the Field of a Series Motor.**—The above statements relate to the use of a rheostat in series with a series-wound motor. If a resistance or rheostat be placed in parallel with the field of a series-wound motor the speed will be increased instead of decreased at a given load. This is known as shunting the field of the motor. This shunt would never be applied till the motor has been brought up to normal full speed by cutting out the starting resistance. With a "shunted field" a motor drives a load at a speed higher than normal and therefore requires a correspondingly increased current.

176. **Shunted Armature Connection of a Series Motor.**—If a resistance is placed in parallel with the armature of a series motor, the motor will operate at less than normal speed when all the starting resistance has been cut out. This connection is known as a "shunted armature connection" and is useful where a low speed is desired at light loads and is particularly useful in some cases where the load becomes a negative one, that is, where the load tends to overhaul the motor, as in lowering a heavy weight.

177. **Speed Control of Shunt-wound Motors.**—A shunt-wound motor, unlike a series motor, when supplied with full voltage, maintains practically a constant speed regardless of variations in load within the limits of its capacity. It automatically acts like a steam engine having a very efficient governor. The speed of a shunt-wound motor may be decreased below normal by a rheostatic controller in series with its armature and may be increased above normal by means of a rheostat in series with its field winding. The latter rheostat is known as a "field rheostat," and, to be effective, must have a high resistance owing to the small current which flows through the shunt field winding.

178. **Speed Control of Compound-wound Motors.**—A compound-wound motor is a hybrid between a series and shunt-wound motor and its characteristics are likewise of a hybrid nature. A compound-wound motor will not "run away" under no-load as will a series motor, but its speed decreases as the load increases, though not so rapidly as is the case with a series-wound motor. The characteristics of the compound-wound motor render it particularly valuable in cases where the load is subject to wide variation. It will give a strong torque in starting and driving heavy loads and at the same time will not race dangerously when the load is suddenly relieved.

The speed of a compound-wound motor may be reduced below normal by means of a rheostat in the circuit of its armature. The speed may be increased above normal by shunting and even short-

circuiting the series field winding, and may be still further increased by means of a field rheostat in series with the shunt field winding.

179. **In starting a direct-current motor** (see Fig. 73), close the line switch and move the operating arm of the rheostat step by step over the contacts, waiting a few seconds on each contact for the motor speed to accelerate. If this process is performed too quickly the motor may be injured by excessive current; if too slowly, the rheostat may be injured. If the motor fails to start on the first step, move promptly to the second step and if necessary to the third, but no farther. If no start is made when the third step is reached, open the line switch at once, allow the starter handle to return to the off position, and look for faulty connections, overload, etc. The time of starting a motor with full-load torque should not, as a general thing, exceed 15 sec. for rheostats for motors of 5 h.p. and lesser output, and 30 sec. for those of greater output.

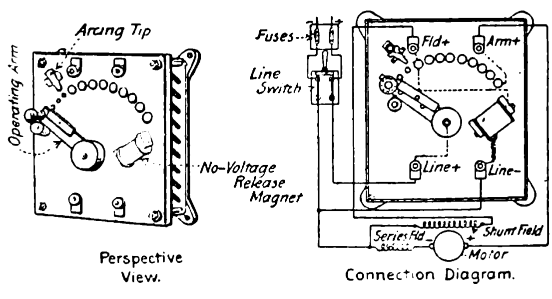


FIG. 73.—Direct-current motor starting rheostat.

180. **In stopping a direct-current motor,** open the line switch. The arm will return automatically to the off position. Never force the operating arm of any automatic-starting rheostat back to the off position.

181. **Starting rheostats for shunt-, compound- and series-wound direct-current motors** vary somewhat in detail, design, and method of connection with the ideas of the different manufacturers. The rheostat shown in Fig. 73 is fairly typical of those for starting motors of outputs up to 120 h.p.

182. **The low-voltage release device on a starting rheostat** consists of a spring, which tends to return the operating arm to the off position, and an electromagnet, which, under conditions of normal voltage, holds the operating arm in the running position. The coil of this magnet is regularly connected across the circuit with a protecting resistance in series, but can be connected in series with the shunt field of the motor if specially required. If the voltage drops below a predetermined value, the arm is released and returned by the spring to the off position.

183. **Arcing Devices on Starting Rheostats.**—Arcing tips consisting of pivoted fingers are sometimes mounted near the point where the circuit is opened. In passing to the off position, a lug on the end of the arm strikes and deflects the tip, which is in electrical connection with the first stationary contact; the current is diverted to the tip, which snaps back when released and opens the circuit very quickly, thus rupturing the arc. Blow-out coils can be mounted behind the first contact and will disrupt any arc formed in opening the circuit.

184. Overload Release Device on Starting Rheostats.—This device, which is not illustrated, includes an electromagnet, which, in case of overload, attracts its armature and forces an insulating wedge between two contacts, separating them and thereby opening the circuit of the low-voltage release magnet. The operating arm returns immediately to the off position. With some devices, the attraction of the armature forces two contacts closed which places a short-circuit around the low-voltage release magnet thereby de-energizing it and permitting the operating arm to return to the off position. It should be noted that the National Code rules require the use of fuses or circuit-breakers with each rheostat even though it be equipped with an overload release of this nature.

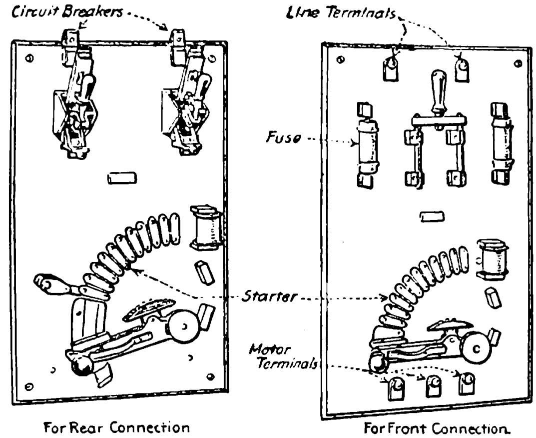


FIG. 74.—Direct-current motor starting panels.

185. Starting panels for direct-current motors are shown in Figs. 74 and 75. Panels, of which the illustrations are typical, are very desirable in that they concentrate all of the apparatus for the motor's control at one point and greatly simplify the wiring. Where such a panel is used it is merely necessary to run the two line wires to the line terminals of the panel and the three leads between the motor and the panel and the installation is ready for operation. The designs of different manufacturers vary in details. The panels can be obtained for either front or rear connection and with circuit-breakers or fuses for overload protection. Which is preferable is determined by the characteristics of the installation in question.

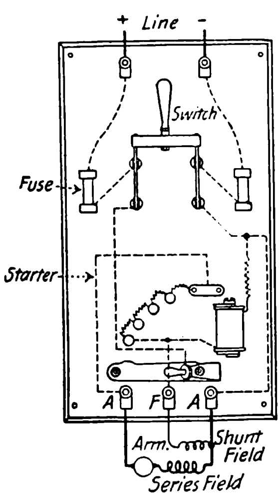


FIG. 75.—Wiring diagram of typical starting panel.

The advantages and disadvantages of protection of each type may be summed thus: (1) Fuses have a time element that circuit-breakers do not have; that is, fuses will not open an overloaded circuit as quickly as circuit-breakers. For this reason fuses may be preferable for motors that are liable to very brief overloads, especially where expert supervision of electrical apparatus is maintained, as in large mills and factories. A supply of extra fuses must be kept available. Where there are many fuse replacements the cost of fuse renewals

is considerable. (2) Circuit-breakers can be reset in less time and with less trouble than is required to replace blown fuses, and no extra parts are required. Circuit-breakers may therefore be preferable where time saving is an important consideration. The first

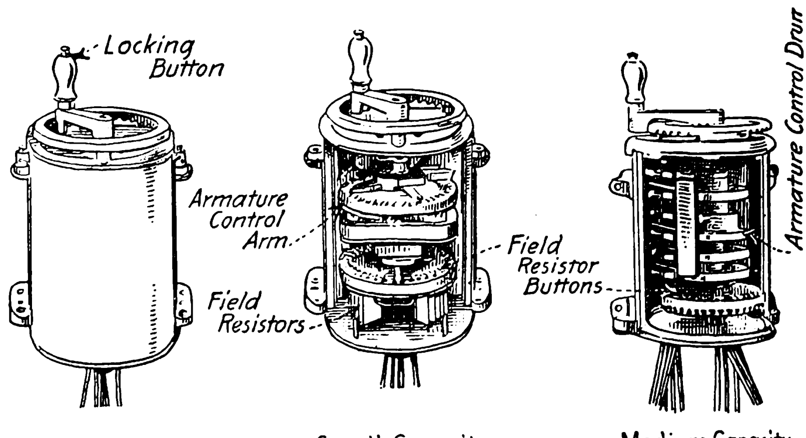


FIG. 76.—Machine tool controller.

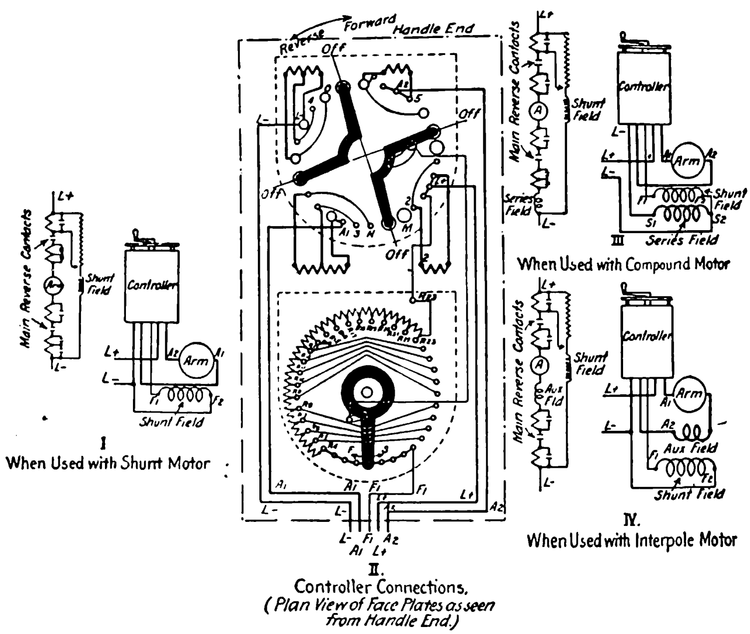


FIG. 77.—Connection diagram for machine tool controller of small capacity using revolving arms for both armature and field control.

cost of the circuit-breaker equipment is more than that for fuses, but for severe service the circuit-breakers are much the cheaper in the long run.

186. Rotary or Machine-tool Type Controllers for Direct-current Motors.—Although controllers of this type (Figs. 76, 77

and 78) find their most frequent applications on machine tools, they are very desirable for any service where the work is severe and where the expense of an enclosed controller is justified. Machine-tool work usually requires a combination starting and speed-regulating controller, that is, one whereby the motor is started by cutting out armature resistance. After the motor is started, its speed is regulated by varying the amount of resistance in series with the shunt field. These controllers can be purchased for this service and for control or starting service of practically any type. The methods of construction and connection are so numerous that only one type of drum controller, one which is used for machine-tool service, will be described here.

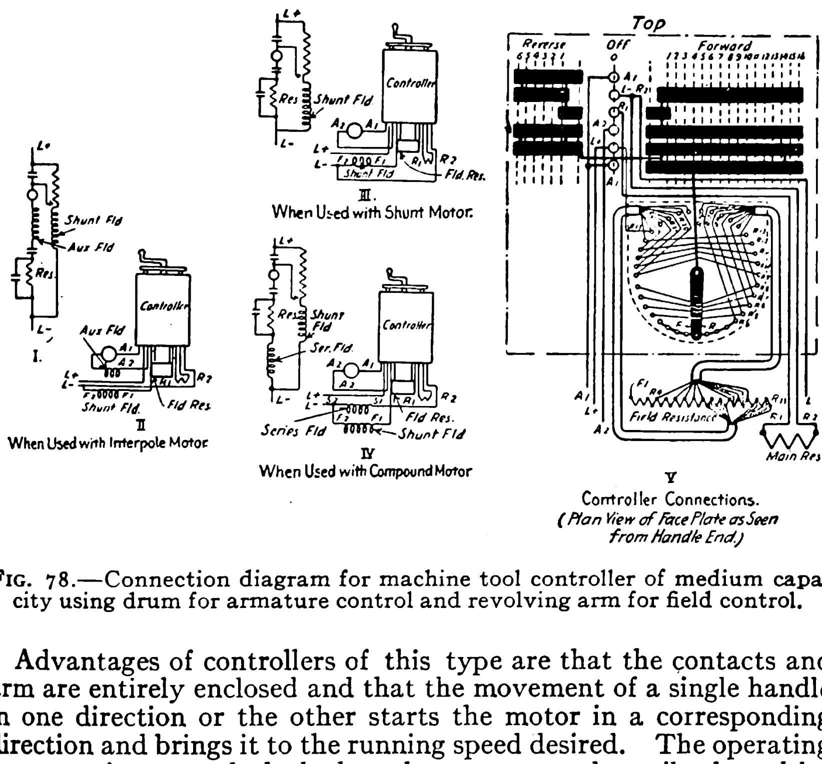


FIG. 78.—Connection diagram for machine tool controller of medium capacity using drum for armature control and revolving arm for field control.

Advantages of controllers of this type are that the contacts and arm are entirely enclosed and that the movement of a single handle in one direction or the other starts the motor in a corresponding direction and brings it to the running speed desired. The operating arm remains securely locked at the proper notch until released by the operator by pressing a button in the handle.

There are two switching devices in the controller shown in Figs. 77 and 78. One connects to the armature or starting resistor and the other connects to the field control resistor. Both switching devices are operated by the same handle. In drum controllers of small capacity the armature switching device consists of an arm passing over contact buttons and all of the resistors are mounted within the drum; that is, the controller is self contained. In controllers of large capacity, the armature resistance is cut in and out by a rotating drum similar to that used in street-railway service and all of the resistors are mounted external to the controller.

The field resistance is cut in and out by a rotating arm passing over contact buttons in all but the largest controllers for which a drum is used. Arc shields between drum segments and blow-out coils are provided where necessary. The controllers can be arranged to provide dynamic braking. Speed ranges of from 1 to 2 to, possibly, 1 to 6 are usually provided.

187. Operation of Rotary or Machine-tool Type Controllers.—(See Figs. 69, 77 and 78.) Continuous movement of the operating handle in either direction first starts the motor in the corresponding direction of rotation, then cuts out the starting resistance, and finally cuts in the field resistance until the desired running speed is reached. The handle should be moved over the starting notches in not over 15 sec. for motors of possibly 10 h.p. capacity and in not over 30 sec. for larger motors. The starting resistance should not be used for speed control.

For a quick stop when operating with weakened field, move the handle quickly to the first running notch, hold it there momentarily and then move it to the off position; the application of full field strength when the speed is high causes dynamic braking, thus checking the speed quickly and without shock. For a very quick emergency stop, the handle can be moved to the first reversing notch after checking the speed by dynamic braking, but this operation causes severe mechanical and electrical stresses; this reversing should never be carried beyond the first notch. When the motor is to be at rest for any length of time, open the line switch.

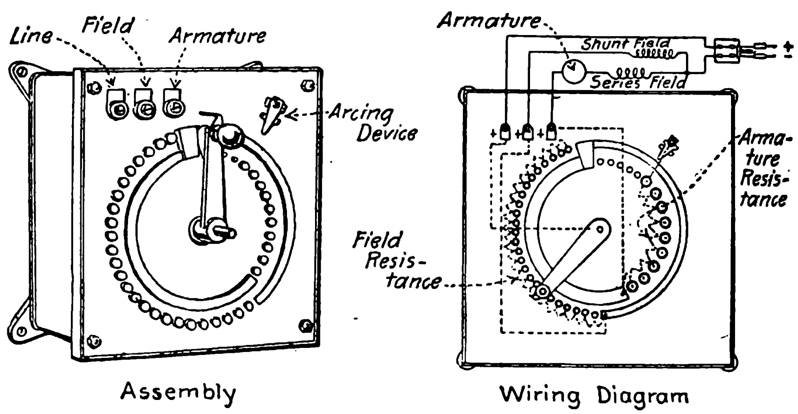


FIG. 79.—Non-automatic starting and speed-adjusting rheostat.

188. A non-automatic starting and speed-adjusting rheostat for direct-current motors is shown in Fig. 79. This device has no low-voltage or overload protection hence is suitable only for applications where skilled attendance is available. The operating arm makes contact as it is revolved between the circular bars and the resistance contact buttons. There are a number of field-control steps, hence close speed adjustment over a considerable range can be obtained. The contact buttons of the inner circular segment are connected to the starting resistor and the contacts of

the outer circle are connected with the running resistor. A reading of the following paragraph describing the operation of the device will render clear the principles involved.

189. Operation of a Non-automatic Starting and Speed-adjusting Rheostat.—(Fig. 79.) To start the motor, close the line switch or circuit-breaker and move the operating arm of the rheostat over the starting buttons to the first running position (the point where the two bar contacts overlap). A motor starting with full-load torque should be brought to this point in approximately 15 sec. Further movement of the operating arm increases the motor speed by field control. The motor can be operated continuously with the arm on any field contact button, but with rheostats of this design must not be allowed to run on any starting button. To stop the motor, open the line switch or circuit-breaker and move the rheostat arm to the off position. The latter movement must not be forgotten, since this rheostat has no automatic features. To protect the motor in case of failure of the power supply and its subsequent return after the motor has stopped, a low-voltage release circuit-breaker should be installed in series with each rheostat. *The rheostat handle must be in the off position* before the circuit-breaker is closed. (*Westinghouse Electric & Manufacturing Company.*)

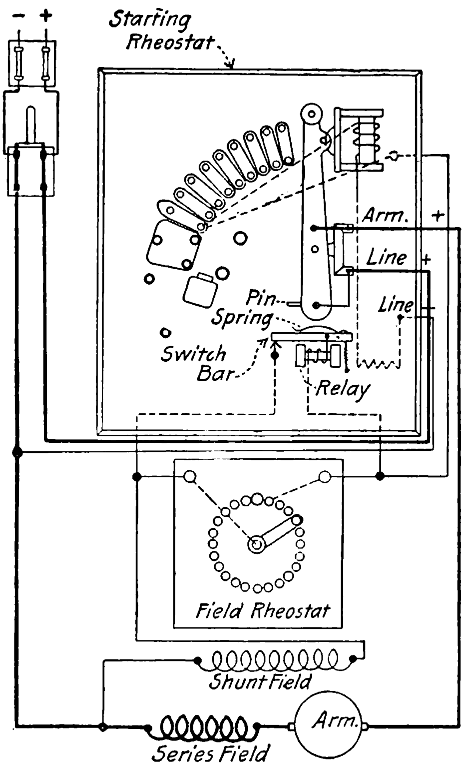


Fig. 80.—Field rheostat relay switch.

190. Field relay switches are required where separate rheostats are used for starting and controlling the speeds of motors. This is required by a National Code rule to prevent the possibility of starting a motor with weakened field. The switch, shown in Fig. 80, mounted under the starter handle accomplishes this function by short-circuiting the field rheostat during acceleration so that the motor must always start with full field regardless of the position of the field rheostat arm. The switch shown, or a similar one, can be applied to ordinary starting and speed-regulating rheostats and generally should be mounted on the rheostat at the factory of the firm that furnishes it.

The field relay switch shown consists of a small electro-magnet,

a pivoted switch bar, and a stationary contact. The switch bar is normally held away from the contact by a helical spring. The magnet coil, switch bar, and contact are in series with a circuit that parallels the field rheostat.

When the operating arm of the starting rheostat is moved to the first step, a pin on its hub presses the relay switch bar against its stationary contact, thus short-circuiting the field rheostat. As the arm is turned the pin on the starter hub soon releases the relay switch bar; but the relay electro-magnet, energized when the contacts close, holds this bar temporarily in place. The winding of the relay electro-magnet is so proportioned that if there is little or no resistance in series with the motor shunt field, the relay magnet will release the switch bar before the motor is brought to full speed, leaving the field rheostat available for speed adjustment. But if the field rheostat arm is turned so that there is more resistance in series with the shunt field than would be safe to insert in one step, the electro-magnet will keep the relay switch closed until the arm of the field rheostat is brought back toward the off position.

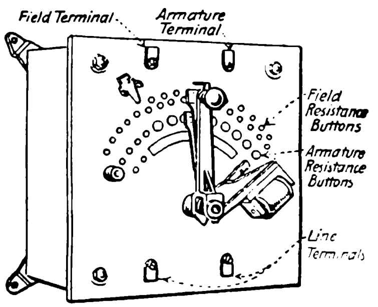


FIG. 81.—Starting and speed-adjusting rheostat.

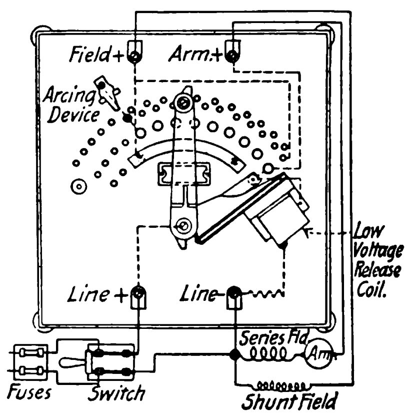


FIG. 82.—Wiring diagram for starting and speed-adjusting rheostat.

191. Starting and Speed-adjusting (Field Control) Rheostats for Direct-current Shunt- and Compound-wound Motors.—There are as many and more designs as there are manufacturers, but the equipment shown in Figs. 81 and 82 is typical and can be used for starting and regulating speed in non-reversing services where speed adjustment by field control is desirable. The apparatus is so arranged that the motor is always started with full field strength. In case of failure of the voltage, the field control resistance is automatically short-circuited and the motor is disconnected from the line.

The rheostat consists of a face plate carrying the contacts, operating arms, and safety devices, mounted in connection with two resistors. One is for starting and one is for adjusting the field strength. The face plate carries three rows of stationary contacts. The upper row is connected with the field adjusting resistor, the second row with the starting resistor; and the lower

row contains a long curved segment for short-circuiting the field resistance in starting. A contact for short-circuiting the armature resistance when the arm is in the running position is sometimes provided.

The face plate supports two arms, an operating arm and a short-circuiting arm, pivoted to the same hub and arranged so that they cannot pass each other. The operating arm carries the handle and two contact fingers, one for the starting contacts and the other for the field contacts. The short-circuiting arm has a contact finger which slides over the contact bar, short-circuiting the field resistance in starting, and the armature resistance while running. In some designs this arm also carries laminated copper brushes which short-circuit the starting resistance when the arm reaches the running position. A spring tends to return the short-circuiting arm to the off position.

Under conditions of normal operation the short-circuiting arm is held in the running position against the force of the spring by an electro-magnet connected across the line in series with a protecting resistance. If the voltage falls below a predetermined point, the arm is released and returns to the off position, carrying the operating arm with it.

Rheostats for this service are frequently arranged so that the circuit is opened between a lug on the operating arm and a small pivoted finger with a centering spring mounted near the first starting contact and connected to it electrically. The current is always broken abruptly no matter how slowly the arm may be moved. Blow-out coils are sometimes mounted on the rear of the face plate to disrupt any arc that may form.

An overload release device can be mounted on all but the largest rheostats of this type. It consists of an electro-magnet which, in event of an overload, opens the low-voltage magnet circuit, thus releasing the short-circuiting arm. The tripping point is adjustable. The National Code rules require the use of a circuit breaker or fuses with a rheostat equipped with an overload release of this character. (*Westinghouse Electric & Manufacturing Company.*)

192. Operation of a Starting and Speed-adjusting Rheostat.—(Figs. 81 and 82.) The motor is started by moving the operating arm to the running position, stopping a few seconds on each starting contact to permit the speed to accelerate. The retaining magnet holds the short-circuiting arm in the running position where it short-circuits the starting resistor. The operating arm is then moved back over the field-resistance contacts until the desired speed is reached. For motors starting with full-load torque, the time of acceleration should be from 15 sec. to 30 sec., depending upon the capacity of the motor. To stop the motor, open the line switch. Both arms then return to the off position automatically.

193. Armature control speed regulators (Fig. 83) are used for speed reduction with shunt, compound or series motors in non-reversing service where the torque required decreases with the speed but remains constant at any given speed as with fans, blowers and centrifugal pumps. They can also be used for applications where the torque is independent of the speed, as with job

printing presses. However, this method of speed control is not suitable for such applications where there is operation for long periods at reduced speed, since such operation is not economical. It is not possible, where the torque varies, to obtain constant speed with these controllers.

In the regulator shown the low-voltage release consists of an electro-magnet enclosed in an iron shell, a sector on the pivot end of the operating arm, and a strong spring which tends to return the arm to the off position. The magnet is mounted directly below the pivot of the arm and its coil is connected in shunt across the line in series with a protecting resistance. When the magnet is energized its plunger rises and forces a steel ball into one of a series of depressions in the sector on the arm with sufficient force to hold the arm

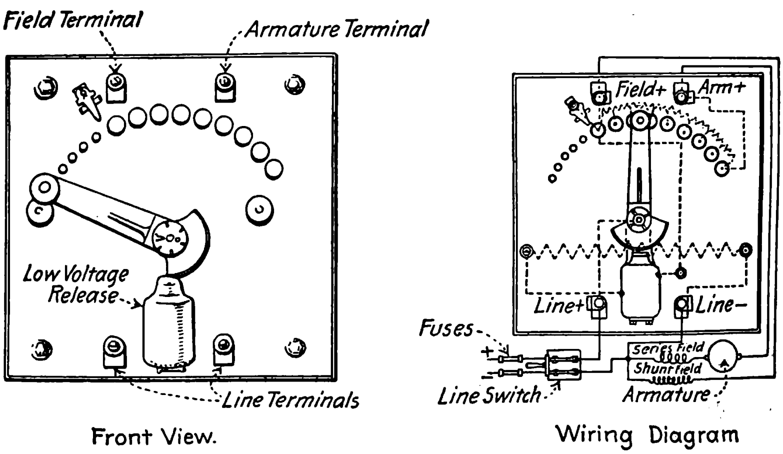


FIG. 83.—Armature control speed regulator.

against the action of the spring; each depression corresponds to a contact. The arm can be easily moved by the operator, however, as the ball rolls when the arm is turned. When the voltage fails, the magnet plunger falls and the spring throws the operating arm to the off position. An overload release, similar to that described in another paragraph, which operates by opening the low-voltage coil circuit, is sometimes furnished on regulators of this type. Standard commercial rheostats of this type are designed to give about 50 per cent. speed reduction on the first notch. See the following paragraph on operation for further information.

194. Operation of Armature Control Speed Regulators.—(Fig. 83.) Continuous motion of the operating arm starts the motor and brings it gradually to maximum speed. Moving the arm over the first few contact buttons increases the shunt field strength if the motor is shunt or compound. The movement over the succeeding buttons cuts out armature resistance and permits the motor to speed up.

195. Objections to Armature Control (*Crocker and Arendts, Electric Motors*). (a) *Bulk of Rheostat.*—This may not be very

objectionable if only a few motors are so controlled, but for a number the extra space becomes a factor, and in many cases it is difficult to find sufficient room near the motor.

(b) *Inefficiency of the System.*—The same amount of power is supplied at all speeds, but at low speeds only a small part of it is converted into useful work, the balance being wasted in the rheostat as heat.

(c) *Poor Speed Regulation with Varying Loads.*—Since the impressed voltage at the armature terminals is equal to the line voltage minus the resistance drop in the rheostat ($V_t = V - I_a R_x$), any change in the current drawn by the motor produces a change in the terminal voltage, the counter e.m.f., and therefore the speed.

196. Crane controllers for direct-current series and compound-wound motors are usually arranged somewhat as indicated in Fig. 84. The switching device consists of a disc of soapstone or other fire-proof insulating material carrying stationary contact pieces and a pivoted switch arm carrying four contactors. Blow-out coils are usually provided to effectively rupture the arcs that form when the contactors pass from one contact piece to the next. The resistors may be contained in the controller base, as in small controllers, or may be arranged for separate mounting as in large ones. In Fig. 84 the fine lines within the circle are shading lines which merely indicate that the circle is a soap stone disc. Only the heavy lines within the circle represent electrical connections. Fig. 85 shows two typical controllers.

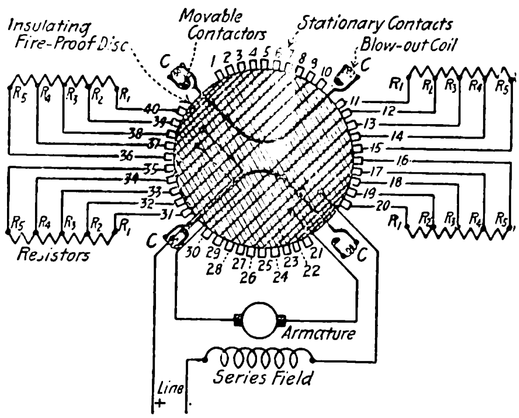


FIG. 84.—Connections of a 16-point crane controller connected to a series motor.

Movement of the controller handle in either direction past the off position starts the motor in the corresponding direction of rotation. At each step a section of resistance is short-circuited. At the full-speed positions all the resistance is short-circuited. Stops prevent over-running past the full-speed positions. Direct-current crane controllers increase or decrease the amount of resistance in series with the motor and thereby control its speed.

197. Dynamic braking of direct-current motors is effected by allowing a motor to be temporarily driven as a generator by its load. The mechanical energy of the moving machinery or descending load is thus converted into electrical energy and then into heat which is dissipated in resistance. The result is that the speed of the motor is promptly retarded. The amount of braking action can be adjusted by varying the current flowing in the motor armature.

A load exercising an active torque on the motor armature, such as an elevator car, cannot be brought to a full stop by this method, since with the decreasing armature speed the braking action also decreases. For final stopping, some form of mechanical brake, which acts automatically, is therefore necessary.

Dynamic braking is used in connection with motors for elevators, hoists, cranes, coal and ore handling machinery, railway cars, etc. It is employed for reducing the motor speed just before a stop, as in elevator service; or for controlling the speed of moving objects, as in lowering crane loads, retarding the speed of the cars descending grades, etc.

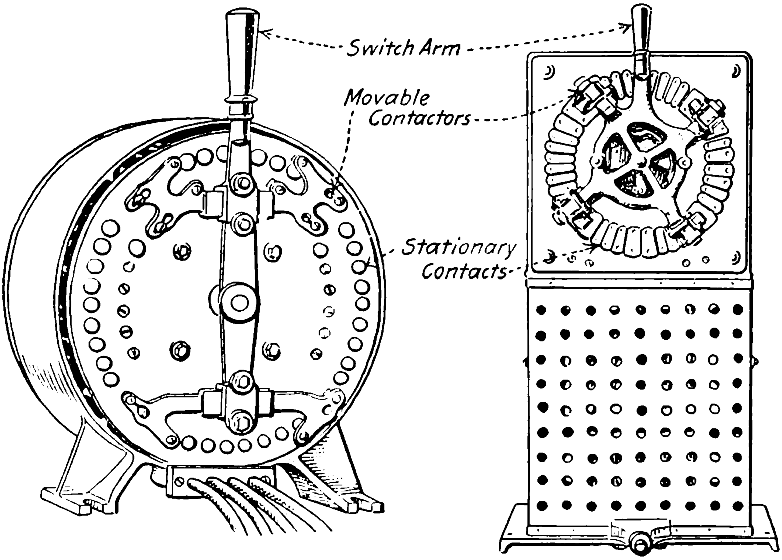


FIG. 85.—Crane controllers.

198. The principal advantages of dynamic braking are the practical absence of all wear and tear on the apparatus, convenience of application, and ease, accuracy, and certainty of control. In dynamic braking with a properly selected motor, active deterioration is limited to the controller contacts, which can be arranged for quick, easy, and inexpensive renewal. No special or additional apparatus is required for braking except the resistance which can be placed wherever convenient within a reasonable distance from the motor. The braking effect can be adjusted with great accuracy over a wide range by varying the armature current or the field strength by means of suitable resistance.

In some instances, notably with railroads, dynamic braking actually returns energy to the circuit; but in industrial service the energy generated is usually dissipated by resistance. In electric cars, during the winter months this dynamic braking current is in many cases run through heaters for warming the cars.

199. Heating with Dynamic Braking.—The most important limitation to the use of dynamic braking is the heating of the motor by the generated currents. For simple stopping duty this action

is insignificant as it lasts only a few seconds; but with speed control in lowering a load by dynamic braking, the generated current may flow for an extended length of time and the heating may be considerable, especially as it is added to the heating of the machine when operated as a motor. This additional heating effect due to the braking current must be considered in selecting the motor.

200. **Dynamic-braking Connections.**—Fig. 86 shows by simple diagrams some of the possible connections. Diagram *I* shows the armature of a shunt motor short-circuited through a brake resistance, the field remaining across the line. Diagram *II* shows the

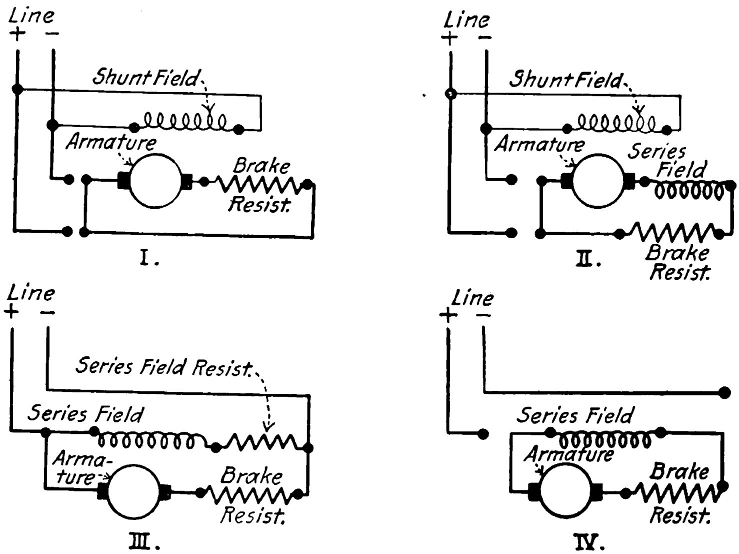


FIG. 86.—Dynamic braking connections.

armature of a compound motor short-circuited through the series field and a brake resistance, the shunt field remaining across the line. Diagram *III* shows the armature of a series motor short-circuited through the series field, a protecting resistance for the field, and a brake resistance—the field and its resistance being in series across the line. Diagram *IV* shows the armature and series field of a series motor short-circuited through a brake resistance, all of which are entirely disconnected from the line.

By cutting out the series field in diagram *II* the braking effect can be diminished, the connections then being as in *I*. The connections shown in diagram *III* are generally preferable for series motors during the first part of the braking operation, in order to insure building up as a generator. As soon as the generator action has begun, the connections can be changed to those shown in diagram *IV*. In each of the cases shown by the four diagrams the braking effect can be increased by short-circuiting sections of the brake resistance and thus increasing the armature current.

201. **The methods of starting induction motors** may be listed as follows:

(1) *By Connecting Directly to the Line.*—This method is ordi-

narily used only for small motors—those of less than 10 h.p. output—because on starting the motor takes an excessive current and the voltage regulation will be disturbed unless there is ample generating capacity and the conductors are of a generous cross-section.

(2) *By Inserting Internal Resistance in the Rotor Circuit.*—This method is used only with wound rotor machines. The resistance is cut in or out of the circuit by the operation of a switch on the motor shaft so arranged that the handle of the switch is stationary when the rotor is turning.

(3) *By Introducing External Resistance in the Rotor Circuit.*—This method can be used only with a wound-rotor machine having collector rings upon which brushes bear that connect with the resistance. The resistance is cut in or out of the rotor circuit by a controller somewhat similar to the ordinary direct-current motor controller.

(4) *By Using a Transformer having Low-voltage Taps.*—A low voltage can be impressed on the motor at starting by connecting it with a suitable switch to the low-voltage taps.

(5) *With a Starting Compensator or Auto-transformer.*—This is the usual method for motors of ordinary capacity and is similar to the transformer method in that low voltage from the compensator taps are impressed on the motor at starting.

(6) *By Connecting the Armature Coils in Star for Starting and in Delta for Running.*—This method is described in detail in a following paragraph.

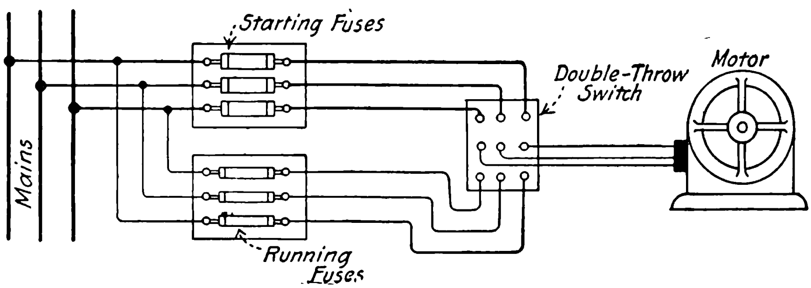


FIG. 87.—Starting small motor by throwing directly on the line.

202. A small induction motor can be started by throwing it directly on the line. (Fig. 87.) This method is, as a general thing, not used for motors of capacities exceeding 5 h.p. Two sets of fuses should be provided, one for starting and one for running, with a double-throw switch to connect the motor to either set. A switch having a spring so arranged that the blades will not remain in the starting position unless manually held there should be used. The starting current of an induction motor thrown directly on the line will be something between three and eight times the full-load running current. If only one set of fuses is used for a polyphase motor and they are of sufficient capacity to carry the starting current, one fuse may open but the motor will continue to operate on one phase, drawing a current considerably above normal. The probable result is a burnt-out motor.

203. Self-contained starters for wound-rotor induction motors of relatively small capacity (Figs. 88 and 89) can be purchased. The resistors for these are mounted within the enclosing case that carries the switching mechanism that increases or decreases the amount of effective resistance in the rotor circuit. As a rule, the resistors in these starters are designed only for starting service,

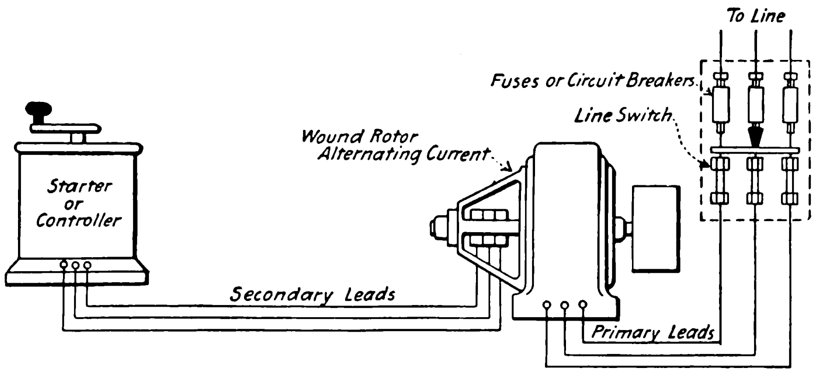


FIG. 88.—Connections of starter to wound rotor motor.

hence they can be used only where starts are infrequent and starting conditions are not severe. They are not usually designed for speed control for which service drum-type controllers with externally mounted resistances are used.

In the usual designs a set of resistors is connected with each phase of the motor (Fig. 90) secondary and all three are interconnected in star by the frame of the starter which is grounded, protecting the operator against shocks.

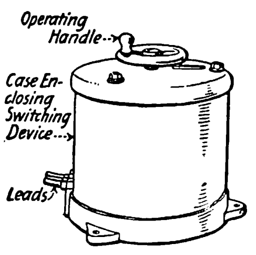


FIG. 89.—Enclosed starter for a phase-wound motor.

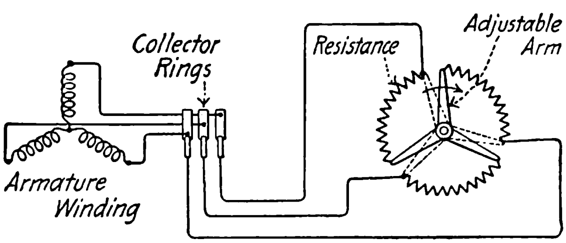


FIG. 90.—Method of varying rotor resistance of a wound rotor induction motor.

204. In operating a self-contained starter for a wound-rotor motor (Figs. 88 and 89) before closing the primary line switch or breaker, the handle of the starter must be in the starting position, where all the starting resistance is in circuit. If the connections are correct, and the load is not too great, the motor should start as soon as the line switch is closed; on failure to start, open the primary circuit, and examine the load conditions and the connections. With some starters the handle may have to be advanced

slightly beyond the starting position before the motor starts. As the motor speed accelerates the starter handle should be moved gradually to the running position, bringing the motor to full speed within the time which is usually specified by the manufacturer of the starter. In the running position all starting resistance is, in starters of most designs, short-circuited.

205. Starting a Coil-wound Rotor Motor (*Southern Electrician*) —With the coil-wound rotor, high and variable starting torque can be obtained by inserting a variable ohmic resistance directly in the rotor circuit. The rotor circuit is connected to a non-inductive resistance, which can be varied and gradually cut out as the motor attains speed. Figs. 90 and 91 illustrate the connections. When the rheostat handle is in the extreme left-hand position, the resistance is all out of circuit.

To start the motor, current is first switched on to the stator circuit by closing a triple-pole switch. The three-pole contact blades of the starting rheostat are now moved over from the off position on to the resistance studs, the first contacts of which place the whole of the resistance in circuit with the respective three-phase windings of the rotor. This prevents the current induced in the rotor windings by the stator circuit from reaching an excessive amount. The switch handle on being further rotated in a right-handed direction gradually cuts out the resistance until all the resistance is out of circuit. In this position the rotor windings are short-circuited.

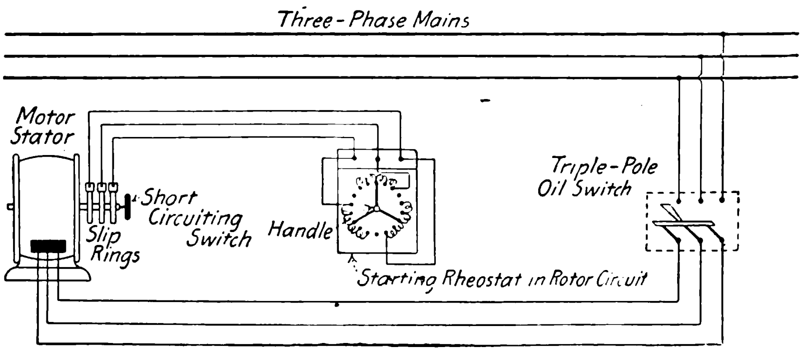


FIG. 91.—Starting arrangement for three-phase coil-wound rotor motor.

206. Commercial starting compensators for squirrel cage induction motors usually have three positions at which the starting lever will come to rest—an "off" position, a "starting" position, and a "running" position. The lever is so arranged that the switch that it controls cannot come to rest in any other positions unless forcibly restrained. The connections of a two-phase and of a three-phase compensator are shown in connection with the material on auto-transformers in Sect. V, *Transformers*. Connection arrangements for compensators of other types are shown on pages adjacent hereto.

In starting compensators, as usually arranged, when in the "off"

position the switch is open and the motor and auto-transformer are entirely disconnected from the source of energy. When in the "starting" position, the source of energy is directly connected by the switch to the auto-transformer terminals and the low voltage taps of the auto-transformer are connected to the motor. Usually there are no fuses inserted in the starting leads at the compensator.

When thrown to the "running" position the switch connects the motor through fuses to the source of energy and the auto-transformer is entirely disconnected from the source of energy. The fuses provided in the running leads are for the protection of the motor against overload while it is in normal operation. The fuses protecting the tap circuit to the compensator where the tap circuit branches from the main are usually depended upon to protect the motor while it is starting.

207. Starting With and Without Compensators.—The starting current taken by a squirrel cage induction motor at the instant of starting is equal to the applied electro-motive force divided by the impedance of the motor. Only the duration of this current, and not its value, is affected by the torque against which the motor is required to start. The effect of starting without and with a compensator is illustrated by diagrams *I* and *II* in Fig. 92. In this diagram, motor *I* is thrown directly on a 100-volt line. The impedance of the motor is 5.77 ohms per phase, the starting torque 10 lb. at 1 ft. radius and the current taken 10 amp. In diagram *II* a compensator is inserted, stepping down the line pressure from 100 to 50 volts. This reduces the starting current of motor one-half and the starting torque becomes one-quarter

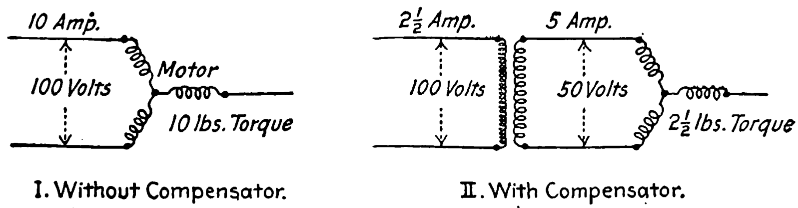


FIG. 92.—Starting with and without compensator.

its previous value or 2½ lb. at 1 ft. radius. The current in the line is reduced inversely as the ratio of transformation in the compensator and becomes 2½ amp.

Thus when a compensator is used the starting torque of the motor can be reduced to approximately the value required by the load and the current taken from the line correspondingly decreased. Where a compensator is not used an increase of rotor resistance results in a proportional increase in the starting torque of the motor with a very slight decrease in the starting current drawn from the line. Where a compensator is used with a motor having a high-resistance rotor the voltage can be reduced to a lower value than would be required with a low-resistance rotor for the same starting torque. Standard compensators are provided with several taps from which various combinations can be obtained.

208. Comparison of Auto-transformer and Resistance for Decreasing Voltage for Starting Squirrel Cage Motors.—The motor in Fig. 93 is supposed to require 100 amp. to start it; that is, to provide the energy necessary to produce the necessary starting torque. At *I*, where an auto-transformer is used to lower the

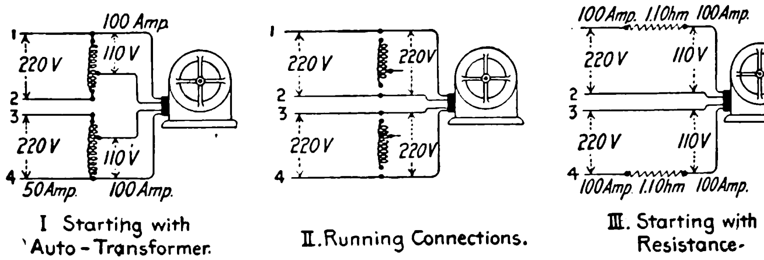


FIG. 93.—Starting with resistance and with compensator.

voltage to 110, a current of 100 amp. is produced in the motor primary with a current in the line of 50 amp. This condition is due to the transformer action of the auto-transformer. At *II* the running connections are shown wherein the auto-transformer is entirely disconnected from the circuit. At *III* are illustrated the conditions that would obtain were the voltage lowered for starting by inserting resistance in series with the line. Obviously 100 amp. must flow in all portions of the line even though the resistance of 1.1 ohm reduces the line voltage of 220 to a voltage of 110 which is impressed on the motor. There is a loss of energy in the resistance. Evidently the auto-starter method is preferable because with it the line current is reduced and there is practically no loss of energy. Although the example illustrated is for a two-phase motor the principle is the same for a three-phase motor.

209. Approximate Starting Currents and Starting Torques of Squirrel Cage Induction Motors with Different Impressed Voltages Obtained by Using a Compensator Starter.—Starting current and starting torque are expressed in terms of normal full-load current and full-load torque, and impressed voltage is expressed in terms of normal voltage:

Voltage impressed on motor, per cent.	Starting current taken from line, per cent.	Starting torque, per cent.
40	112	32
60	250	72
80	450	128
100	700	200

210. Taps of a Starting Compensator (*Southern Electrician*).—Compensators are usually shipped by their manufacturers connected to the auto-transformer tap giving the lowest torque. If the motor will not start its load with this tap connected the next higher voltage tap should be tried, and so on, until the tap is found that provides the required torque.

Compensators for use with motors of 15 h.p. and under sometimes have three taps giving voltages of 40 per cent., 60 per cent. and 80 per cent. of full-line impressed voltage. For motors above 15 h.p., four taps are frequently provided giving 40, 58, 70 and 85 per cent. of full-line voltage. The proper tap for giving the maximum starting torque without causing an inconvenient voltage disturbance in the supply circuit, can best be ascertained by experiment.

One make of compensator has for motors of from 5 to 18 h.p., taps starting the motor at 50, 65 and 80 per cent. of the full impressed line voltage, with respective line currents equal to 25, 42 and 65 per cent. of the current that would be taken by the motor if no compensator were used. For motors larger than 18 h.p., compensator-voltage taps are provided giving voltages equal to 40, 58, 70 and 85 per cent. of the full impressed line voltage, and respective currents approximately equal to 16, 34, 50 and 72 per cent. of the current that would be taken by the motor if it were started directly from the supply line.

211. **Starting compensators for motors of high-voltage or large current capacity** are arranged with the switches separate from the auto-transformer (Fig. 94). The equipment usually consists of one double-throw or two interlocked single-throw oil switches

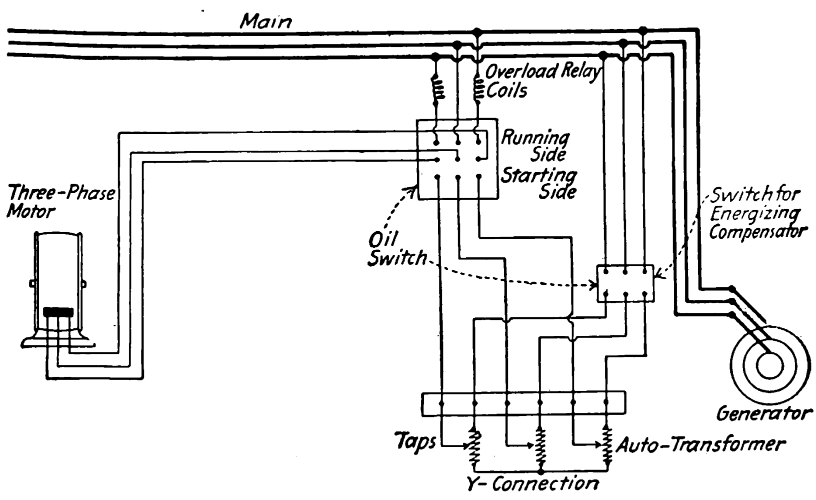


FIG. 94.—Starting compensator with separate switches, and auto-transformer for high-voltage or large capacity motor.

for the motor and a single-throw oil switch for energizing the auto-transformer. In the running leads to the motor may be inserted overload relays which will open the oil switches in case of over-draught of current. The oil switches are usually mounted on a switchboard panel while the auto-transformer may or may not be mounted on the panel. The construction indicated in the other compensator diagrams is used by certain manufacturers for motors of capacities up to and including 550 volts when the normal current does not exceed 300 amp. per phase and for motors of from

printing presses. However, this method of speed control is not suitable for such applications where there is operation for long periods at reduced speed, since such operation is not economical. It is not possible, where the torque varies, to obtain constant speed with these controllers.

In the regulator shown the low-voltage release consists of an electro-magnet enclosed in an iron shell, a sector on the pivot end of the operating arm, and a strong spring which tends to return the arm to the off position. The magnet is mounted directly below the pivot of the arm and its coil is connected in shunt across the line in series with a protecting resistance. When the magnet is energized its plunger rises and forces a steel ball into one of a series of depressions in the sector on the arm with sufficient force to hold the arm

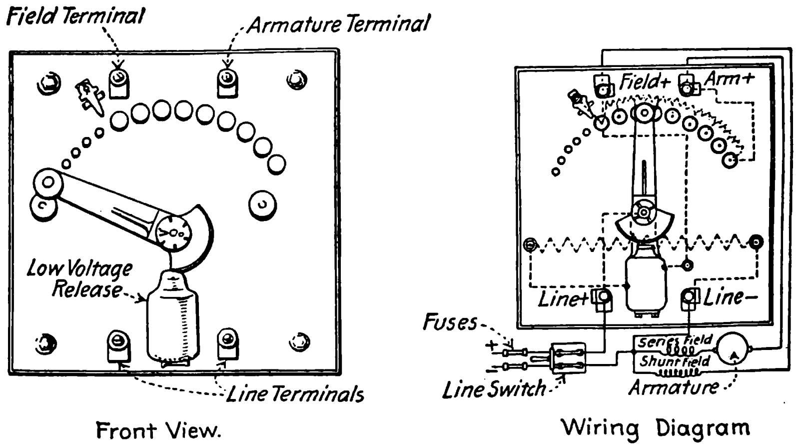


FIG. 83.—Armature control speed regulator.

against the action of the spring; each depression corresponds to a contact. The arm can be easily moved by the operator, however, as the ball rolls when the arm is turned. When the voltage fails, the magnet plunger falls and the spring throws the operating arm to the off position. An overload release, similar to that described in another paragraph, which operates by opening the low-voltage coil circuit, is sometimes furnished on regulators of this type. Standard commercial rheostats of this type are designed to give about 50 per cent. speed reduction on the first notch. See the following paragraph on operation for further information.

194. **Operation of Armature Control Speed Regulators.**—(Fig. 83.) Continuous motion of the operating arm starts the motor and brings it gradually to maximum speed. Moving the arm over the first few contact buttons increases the shunt field strength if the motor is shunt or compound. The movement over the succeeding buttons cuts out armature resistance and permits the motor to speed up.

195. **Objections to Armature Control** (*Crocker and Arendts, Electric Motors*). (a) *Bulk of Rheostat.*—This may not be very

objectionable if only a few motors are so controlled, but for a number the extra space becomes a factor, and in many cases it is difficult to find sufficient room near the motor.

(b) *Inefficiency of the System.*—The same amount of power is supplied at all speeds, but at low speeds only a small part of it is converted into useful work, the balance being wasted in the rheostat as heat.

(c) *Poor Speed Regulation with Varying Loads.*—Since the impressed voltage at the armature terminals is equal to the line voltage minus the resistance drop in the rheostat ($V_t = V - I_aR_x$), any change in the current drawn by the motor produces a change in the terminal voltage, the counter e.m.f., and therefore the speed.

196. Crane controllers for direct-current series and compound-wound motors are usually arranged somewhat as indicated in Fig. 84. The switching device consists of a disc of soapstone or other fire-proof insulating material carrying stationary contact pieces and a pivoted switch arm carrying four contactors. Blow-out coils are usually provided to effectively rupture the arcs that form when the contactors pass from one contact piece to the next. The resistors may be contained in the controller base, as in small controllers, or may be arranged for separate mounting as in large ones. In Fig. 84 the fine lines within the circle are shading lines which merely indicate that the circle is a soap stone disc. Only the heavy lines within the circle represent electrical connections. Fig. 85 shows two typical controllers.

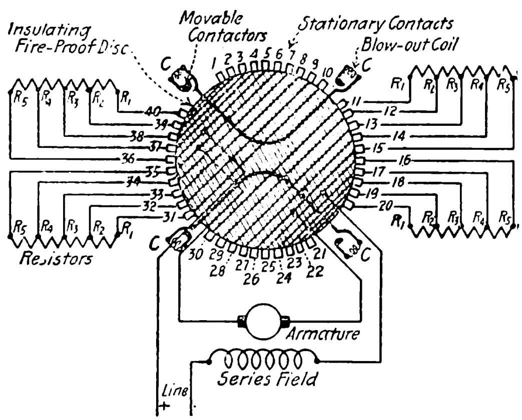


FIG. 84.—Connections of a 16-point crane controller connected to a series motor.

Movement of the controller handle in either direction past the off position starts the motor in the corresponding direction of rotation. At each step a section of resistance is short-circuited. At the full-speed positions all the resistance is short-circuited. Stops prevent over-running past the full-speed positions. Direct-current crane controllers increase or decrease the amount of resistance in series with the motor and thereby control its speed.

197. Dynamic braking of direct-current motors is effected by allowing a motor to be temporarily driven as a generator by its load. The mechanical energy of the moving machinery or descending load is thus converted into electrical energy and then into heat which is dissipated in resistance. The result is that the speed of the motor is promptly retarded. The amount of braking action can be adjusted by varying the current flowing in the motor armature.

A load exercising an active torque on the motor armature, such as an elevator car, cannot be brought to a full stop by this method, since with the decreasing armature speed the braking action also decreases. For final stopping, some form of mechanical brake, which acts automatically, is therefore necessary.

Dynamic braking is used in connection with motors for elevators, hoists, cranes, coal and ore handling machinery, railway cars, etc. It is employed for reducing the motor speed just before a stop, as in elevator service; or for controlling the speed of moving objects, as in lowering crane loads, retarding the speed of the cars descending grades, etc.

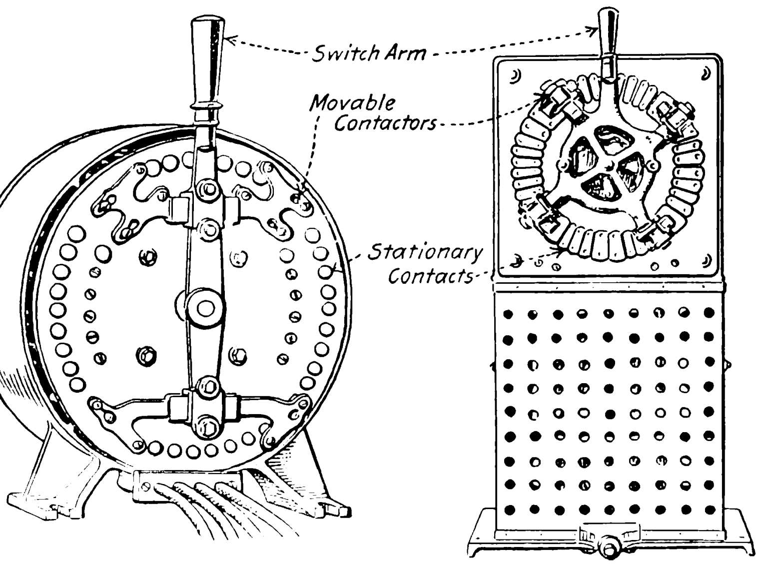


FIG. 85.—Crane controllers.

198. The principal advantages of dynamic braking are the practical absence of all wear and tear on the apparatus, convenience of application, and ease, accuracy, and certainty of control. In dynamic braking with a properly selected motor, active deterioration is limited to the controller contacts, which can be arranged for quick, easy, and inexpensive renewal. No special or additional apparatus is required for braking except the resistance which can be placed wherever convenient within a reasonable distance from the motor. The braking effect can be adjusted with great accuracy over a wide range by varying the armature current or the field strength by means of suitable resistance.

In some instances, notably with railroads, dynamic braking actually returns energy to the circuit; but in industrial service the energy generated is usually dissipated by resistance. In electric cars, during the winter months this dynamic braking current is in many cases run through heaters for warming the cars.

199. Heating with Dynamic Braking.—The most important limitation to the use of dynamic braking is the heating of the motor by the generated currents. For simple stopping duty this action

is insignificant as it lasts only a few seconds; but with speed control in lowering a load by dynamic braking, the generated current may flow for an extended length of time and the heating may be considerable, especially as it is added to the heating of the machine when operated as a motor. This additional heating effect due to the braking current must be considered in selecting the motor.

200. Dynamic-braking Connections.—Fig. 86 shows by simple diagrams some of the possible connections. Diagram *I* shows the armature of a shunt motor short-circuited through a brake resistance, the field remaining across the line. Diagram *II* shows the

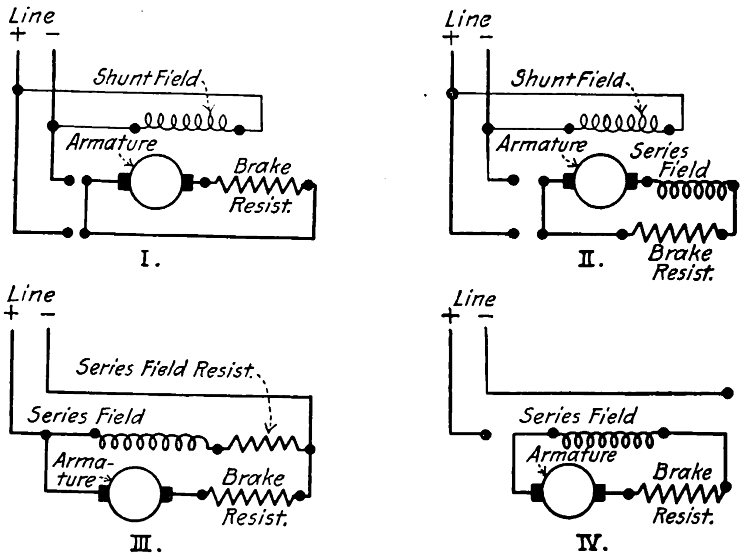


FIG. 86.—Dynamic braking connections.

armature of a compound motor short-circuited through the series field and a brake resistance, the shunt field remaining across the line. Diagram *III* shows the armature of a series motor short-circuited through the series field, a protecting resistance for the field, and a brake resistance—the field and its resistance being in series across the line. Diagram *IV* shows the armature and series field of a series motor short-circuited through a brake resistance, all of which are entirely disconnected from the line.

By cutting out the series field in diagram *II* the braking effect can be diminished, the connections then being as in *I*. The connections shown in diagram *III* are generally preferable for series motors during the first part of the braking operation, in order to insure building up as a generator. As soon as the generator action has begun, the connections can be changed to those shown in diagram *IV*. In each of the cases shown by the four diagrams the braking effect can be increased by short-circuiting sections of the brake resistance and thus increasing the armature current.

201. The methods of starting induction motors may be listed as follows:

(1) *By Connecting Directly to the Line.*—This method is ordi-

narily used only for small motors—those of less than 10 h.p. output—because on starting the motor takes an excessive current and the voltage regulation will be disturbed unless there is ample generating capacity and the conductors are of a generous cross-section.

(2) *By Inserting Internal Resistance in the Rotor Circuit.*—This method is used only with wound rotor machines. The resistance is cut in or out of the circuit by the operation of a switch on the motor shaft so arranged that the handle of the switch is stationary when the rotor is turning.

(3) *By Introducing External Resistance in the Rotor Circuit.*—This method can be used only with a wound-rotor machine having collector rings upon which brushes bear that connect with the resistance. The resistance is cut in or out of the rotor circuit by a controller somewhat similar to the ordinary direct-current motor controller.

(4) *By Using a Transformer having Low-voltage Taps.*—A low voltage can be impressed on the motor at starting by connecting it with a suitable switch to the low-voltage taps.

(5) *With a Starting Compensator or Auto-transformer.*—This is the usual method for motors of ordinary capacity and is similar to the transformer method in that low voltage from the compensator taps are impressed on the motor at starting.

(6) *By Connecting the Armature Coils in Star for Starting and in Delta for Running.*—This method is described in detail in a following paragraph.

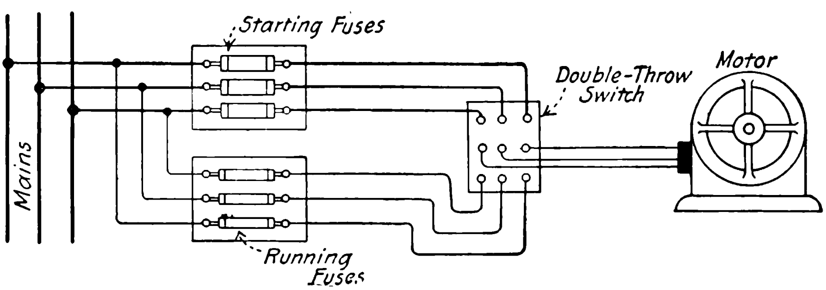


FIG. 87.—Starting small motor by throwing directly on the line.

202. **A small induction motor can be started by throwing it directly on the line.** (Fig. 87.) This method is, as a general thing, not used for motors of capacities exceeding 5 h.p. Two sets of fuses should be provided, one for starting and one for running, with a double-throw switch to connect the motor to either set. A switch having a spring so arranged that the blades will not remain in the starting position unless manually held there should be used. The starting current of an induction motor thrown directly on the line will be something between three and eight times the full-load running current. If only one set of fuses is used for a polyphase motor and they are of sufficient capacity to carry the starting current, one fuse may open but the motor will continue to operate on one phase, drawing a current considerably above normal. The probable result is a burnt-out motor.

203. **Self-contained starters for wound-rotor induction motors of relatively small capacity** (Figs. 88 and 89) can be purchased. The resistors for these are mounted within the enclosing case that carries the switching mechanism that increases or decreases the amount of effective resistance in the rotor circuit. As a rule, the resistors in these starters are designed only for starting service,

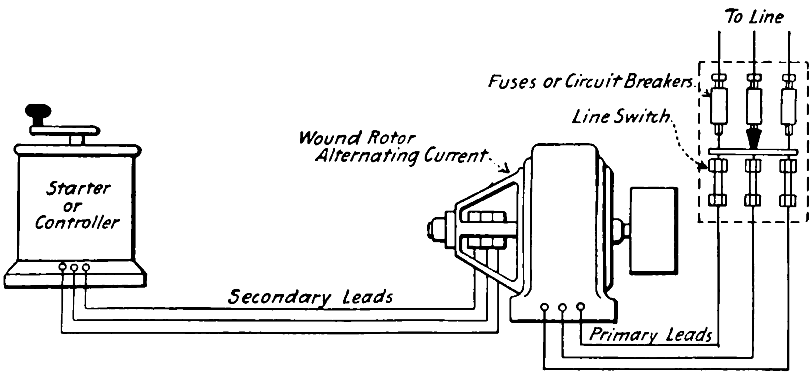


FIG. 88.—Connections of starter to wound rotor motor.

hence they can be used only where starts are infrequent and starting conditions are not severe. They are not usually designed for speed control for which service drum-type controllers with externally mounted resistances are used.

In the usual designs a set of resistors is connected with each phase of the motor (Fig. 90) secondary and all three are interconnected in star by the frame of the starter which is grounded, protecting the operator against shocks.

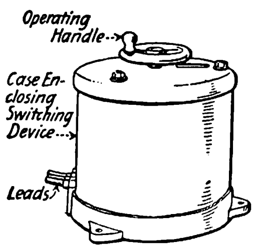


FIG. 89.—Enclosed starter for a phase-wound motor.

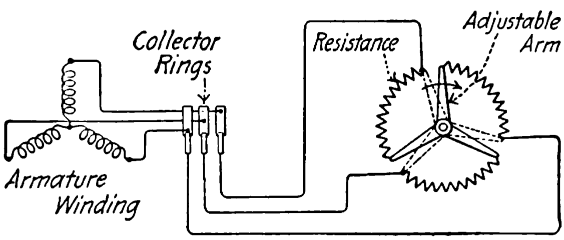


FIG. 90.—Method of varying rotor resistance of a wound rotor induction motor.

204. **In operating a self-contained starter for a wound-rotor motor** (Figs. 88 and 89) before closing the primary line switch or breaker, the handle of the starter must be in the starting position, where all the starting resistance is in circuit. If the connections are correct, and the load is not too great, the motor should start as soon as the line switch is closed; on failure to start, open the primary circuit, and examine the load conditions and the connections. With some starters the handle may have to be advanced

slightly beyond the starting position before the motor starts. As the motor speed accelerates the starter handle should be moved gradually to the running position, bringing the motor to full speed within the time which is usually specified by the manufacturer of the starter. In the running position all starting resistance is, in starters of most designs, short-circuited.

205. Starting a Coil-wound Rotor Motor (*Southern Electrician*)—With the coil-wound rotor, high and variable starting torque can be obtained by inserting a variable ohmic resistance directly in the rotor circuit. The rotor circuit is connected to a non-inductive resistance, which can be varied and gradually cut out as the motor attains speed. Figs. 90 and 91 illustrate the connections. When the rheostat handle is in the extreme left-hand position, the resistance is all out of circuit.

To start the motor, current is first switched on to the stator circuit by closing a triple-pole switch. The three-pole contact blades of the starting rheostat are now moved over from the off position on to the resistance studs, the first contacts of which place the whole of the resistance in circuit with the respective three-phase windings of the rotor. This prevents the current induced in the rotor windings by the stator circuit from reaching an excessive amount. The switch handle on being further rotated in a right-handed direction gradually cuts out the resistance until all the resistance is out of circuit. In this position the rotor windings are short-circuited.

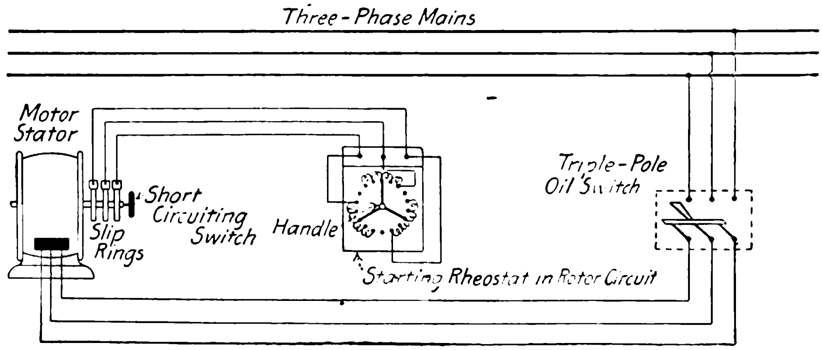


FIG. 91.—Starting arrangement for three-phase coil-wound rotor motor.

206. Commercial starting compensators for squirrel cage induction motors usually have three positions at which the starting lever will come to rest—an "off" position, a "starting" position, and a "running" position. The lever is so arranged that the switch that it controls cannot come to rest in any other positions unless forcibly restrained. The connections of a two-phase and of a three-phase compensator are shown in connection with the material on auto-transformers in Sect. V, *Transformers*. Connection arrangements for compensators of other types are shown on pages adjacent hereto.

In starting compensators, as usually arranged, when in the "off"

position the switch is open and the motor and auto-transformer are entirely disconnected from the source of energy. When in the "starting" position, the source of energy is directly connected by the switch to the auto-transformer terminals and the low voltage taps of the auto-transformer are connected to the motor. Usually there are no fuses inserted in the starting leads at the compensator.

When thrown to the "running" position the switch connects the motor through fuses to the source of energy and the auto-transformer is entirely disconnected from the source of energy. The fuses provided in the running leads are for the protection of the motor against overload while it is in normal operation. The fuses protecting the tap circuit to the compensator where the tap circuit branches from the main are usually depended upon to protect the motor while it is starting.

207. Starting With and Without Compensators.—The starting current taken by a squirrel cage induction motor at the instant of starting is equal to the applied electro-motive force divided by the impedance of the motor. Only the duration of this current, and not its value, is affected by the torque against which the motor is required to start. The effect of starting without and with a compensator is illustrated by diagrams *I* and *II* in Fig. 92. In this diagram, motor *I* is thrown directly on a 100-volt line. The impedance of the motor is 5.77 ohms per phase, the starting torque 10 lb. at 1 ft. radius and the current taken 10 amp. In diagram *II* a compensator is inserted, stepping down the line pressure from 100 to 50 volts. This reduces the starting current of motor one-half and the starting torque becomes one-quarter

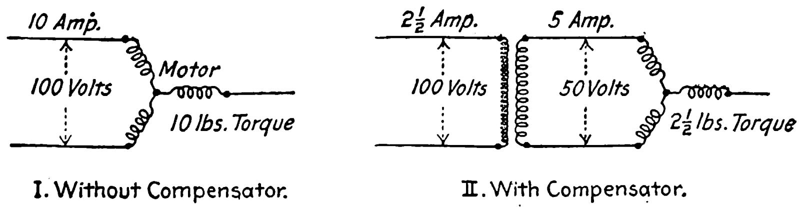


FIG. 92.—Starting with and without compensator.

its previous value or 2½ lb. at 1 ft. radius. The current in the line is reduced inversely as the ratio of transformation in the compensator and becomes 2½ amp.

Thus when a compensator is used the starting torque of the motor can be reduced to approximately the value required by the load and the current taken from the line correspondingly decreased. Where a compensator is not used an increase of rotor resistance results in a proportional increase in the starting torque of the motor with a very slight decrease in the starting current drawn from the line. Where a compensator is used with a motor having a high-resistance rotor the voltage can be reduced to a lower value than would be required with a low-resistance rotor for the same starting torque. Standard compensators are provided with several taps from which various combinations can be obtained.

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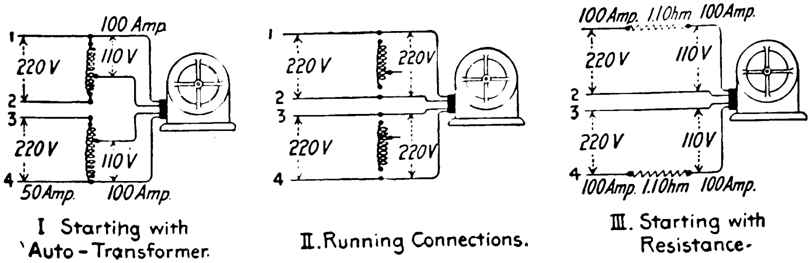

FIG. 93.—Starting with resistance and with compensator.

voltage to 110, a current of 100 amp. is produced in the motor primary with a current in the line of 50 amp. This condition is due to the transformer action of the auto-transformer. At *II* the running connections are shown wherein the auto-transformer is entirely disconnected from the circuit. At *III* are illustrated the conditions that would obtain were the voltage lowered for starting by inserting resistance in series with the line. Obviously 100 amp. must flow in all portions of the line even though the resistance of 1.1 ohm reduces the line voltage of 220 to a voltage of 110 which is impressed on the motor. There is a loss of energy in the resistance. Evidently the auto-starter method is preferable because with it the line current is reduced and there is practically no loss of energy. Although the example illustrated is for a two-phase motor the principle is the same for a three-phase motor.

209. Approximate Starting Currents and Starting Torques of Squirrel Cage Induction Motors with Different Impressed Voltages Obtained by Using a Compensator Starter.—Starting current and starting torque are expressed in terms of normal full-load current and full-load torque, and impressed voltage is expressed in terms of normal voltage:

Voltage impressed on motor, per cent.	Starting current taken from line, per cent.	Starting torque, per cent.
40	112	32
60	250	72
80	450	128
100	700	200

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Compensators for use with motors of 15 h.p. and under sometimes have three taps giving voltages of 40 per cent., 60 per cent. and 80 per cent. of full-line impressed voltage. For motors above 15 h.p., four taps are frequently provided giving 40, 58, 70 and 85 per cent. of full-line voltage. The proper tap for giving the maximum starting torque without causing an inconvenient voltage disturbance in the supply circuit, can best be ascertained by experiment.

One make of compensator has for motors of from 5 to 18 h.p., taps starting the motor at 50, 65 and 80 per cent. of the full impressed line voltage, with respective line currents equal to 25, 42 and 65 per cent. of the current that would be taken by the motor if no compensator were used. For motors larger than 18 h.p., compensator-voltage taps are provided giving voltages equal to 40, 58, 70 and 85 per cent. of the full impressed line voltage, and respective currents approximately equal to 16, 34, 50 and 72 per cent. of the current that would be taken by the motor if it were started directly from the supply line.

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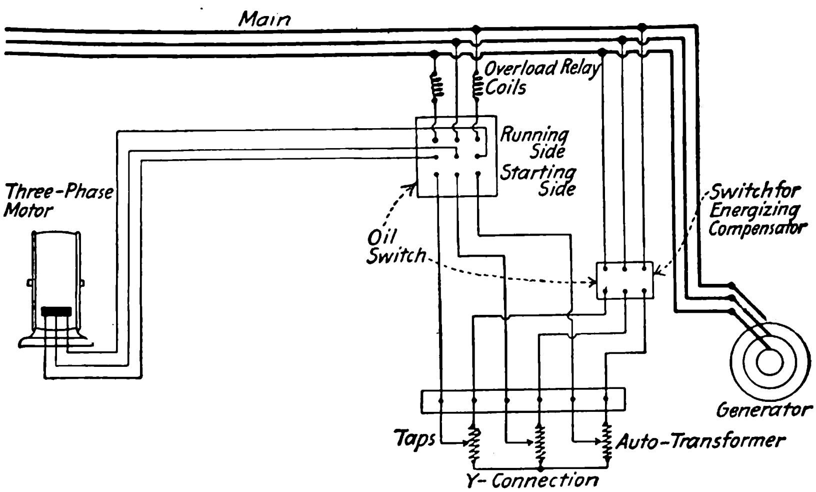


FIG. 94.—Starting compensator with separate switches, and auto-transformer for high-voltage or large capacity motor.

for the motor and a single-throw oil switch for energizing the auto-transformer. In the running leads to the motor may be inserted overload relays which will open the oil switches in case of overdraught of current. The oil switches are usually mounted on a switchboard panel while the auto-transformer may or may not be mounted on the panel. The construction indicated in the other compensator diagrams is used by certain manufacturers for motors of capacities up to and including 550 volts when the normal current does not exceed 300 amp. per phase and for motors of from

1,040 to 2,500 volts with currents not greater than 125 amp. per phase. Where motors take greater normal currents or are of higher voltage the arrangement of Fig. 94 is applied.

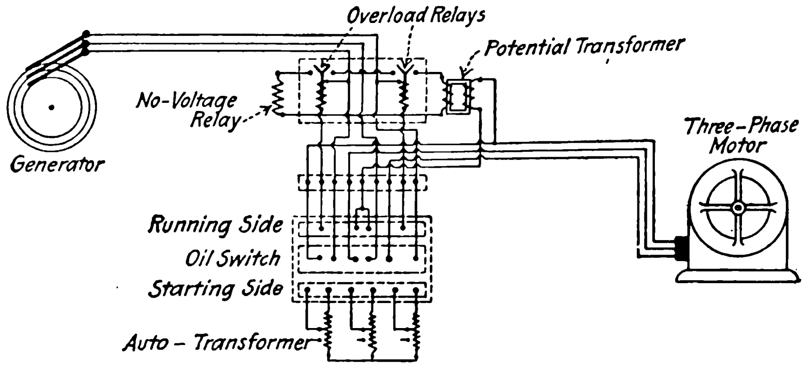


FIG. 95.—Potential transformer for no-voltage relay of high-voltage motor.

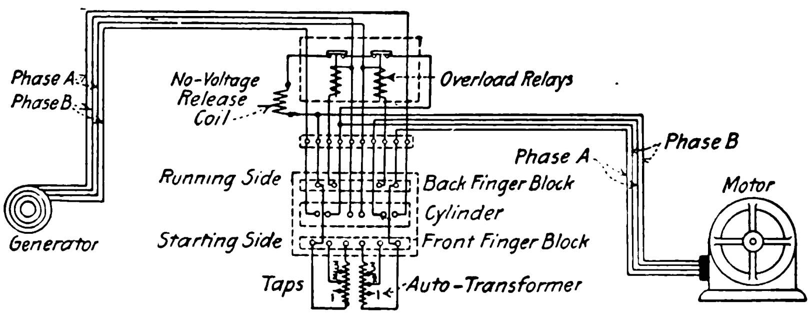


FIG. 96.—Overload relays on a two-phase starting compensator.

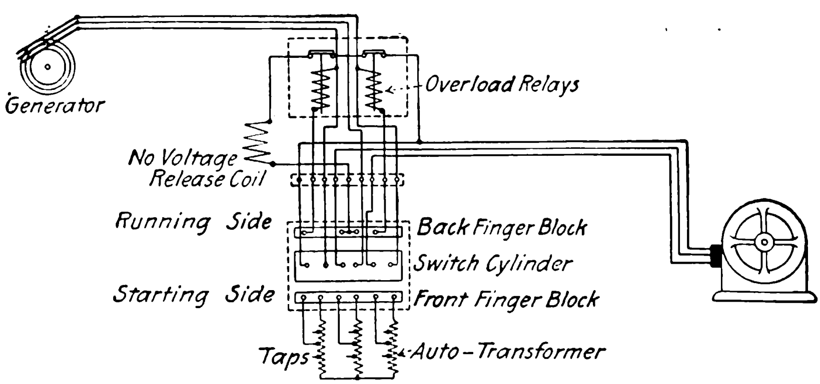


FIG. 97.—Overload release coils on a three-phase starting compensator.

212. **When no-voltage release compensator starters are used for high-voltage motors** a small voltage transformer is usually arranged as in Fig. 95 to energize the no-voltage coil. This ar-

rangement is used by certain manufacturers for compensators, with the no-voltage release attachment, for voltages of from 1,040 to 2,500. The secondary of the transformer furnishes 110 volts for which the no-voltage relay is wound.

213. **Overload release coils on compensators are arranged essentially as shown in Figs. 96 and 97.** When there is an overload on either phase the iron plunger of the overload relay is drawn up which opens the no-voltage release coil circuit. This de-energizes the no-voltage release coil and the compensator circuit is automatically opened as described in the paragraph on the no-voltage release. The overload relays are usually arranged so that they can be adjusted to operate at different currents just as a circuit breaker can be adjusted. An inverse-time-element feature is usually incorporated whereby the relay will operate almost instantly on very heavy overloads but will not operate until a certain interval of time has elapsed (the length of the interval being approximately inversely proportional to the amount of overload) on lesser overloads. It will be noted from the diagrams that fuses are not necessary where the

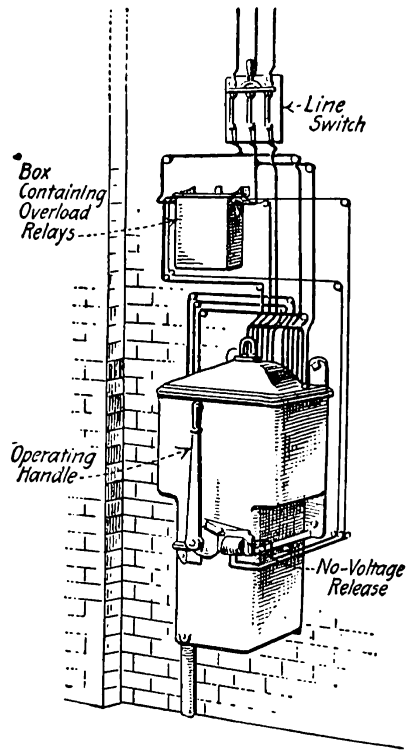


FIG. 98.—Installation of an auto-starter equipped with no-voltage and overload release attachments.

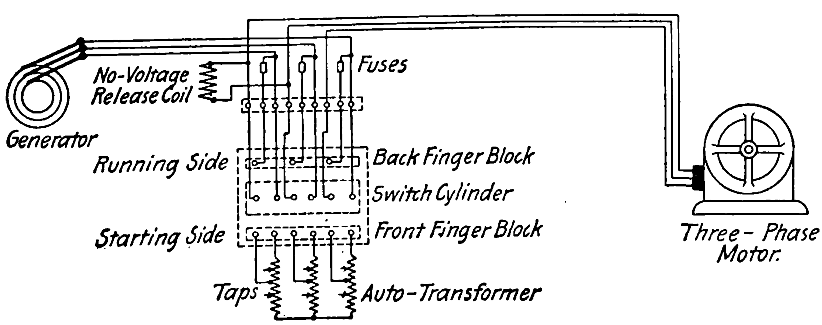


FIG. 99.—Starting compensator with no-voltage release.

overload relays are used. A decided advantage of the overload relays is that they can be adjusted to protect a motor against

running single-phase. If one phase opens, sufficient additional current will be drawn through the others to operate a relay which will open the circuit to the compensator. An installation of a Westinghouse compensator having no-voltage and overload relays is shown in Fig. 98.

214. A no-voltage release can be provided on starting compensators. The connection diagram is shown in Fig. 99 for a three-phase compensator and that for a two-phase compensator is similar. When a condition of no-voltage exists on the line, the *no-voltage release coil* is de-energized which permits the iron armature or core of the no-voltage coil to drop, which automatically releases the compensator handle which is returned to the off position by its spring. This opens the circuit through the compensator.

215. A method of starting several polyphase induction motors from one compensator is shown in Fig. 100. This can frequently be employed to advantage where there are a number of motors situated close together or where a number of motors must be

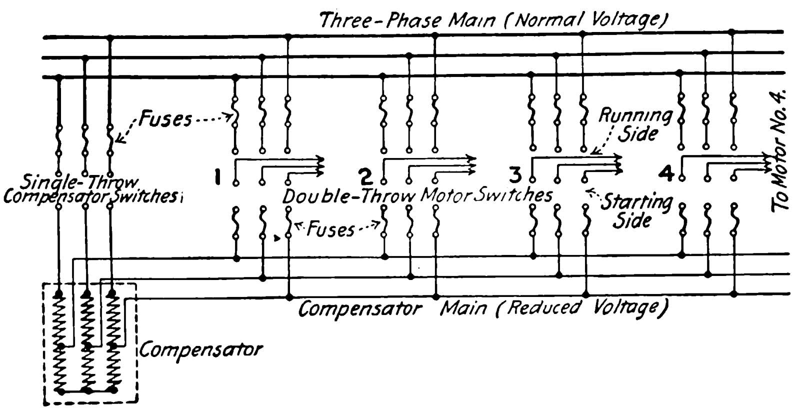


FIG. 100.—Starting several motors from one compensator.

started from one location. A double-throw switch is necessary for each motor to be started and there should be a switch for the compensator. If all of the starting switches are located close together, so that one operator can open or close them consecutively, the compensator need have a capacity only sufficient for serving the largest motor in the group. If the starting switches are so located that several can be operated at once by different men, the compensator must have a sufficient margin of capacity to provide for this. After all of the motors are started the compensator switch is opened, eliminating compensator losses. Where motors exceed possibly 7 h.p. in capacity, oil switches should be used for the starting switches.

216. Fuses for Use in Connection with Compensator Starters.—National Code standard fuses carried in holders mounted on slate bases are usually used for compensators for voltages up to 600 volts. For voltages of from 1,040 to 2,500, if fuses are used, the expulsion type is preferable. A table of fuse sizes for induction

motors is given elsewhere in this book, but where not otherwise specified fuses of a capacity corresponding to $1\frac{1}{4}$ times the full-load current of the motor are supplied.

217. **The delta-star method of starting three-phase, squirrel cage induction motors** is sometimes used (Fig. 101). The stator-coil terminals are brought out from the frame and connected to a double-throw switch as shown. In starting, the coils are connected in star and the current is $\frac{1}{1.73}$ or 0.58 of what it would be with the coils connected in delta. After the rotor has attained full speed the switch is thrown to the running position, which connects the coils in delta and normal voltage is thereby impressed on them. Motors must be specially constructed for this method of starting as it is not extensively used by the principal manufacturers.

218. **Speed Control of Polyphase Motors** (*B. G. Lamme*).—The speed of polyphase motors can be controlled by a number of different methods, of which the following are the most important. I. Adjusting the resistance of the secondary circuit. II. Adjusting the primary voltage. III. Using two motor primaries, one of which is capable of being rotated. IV. Changing the number of motor poles. V. Operating two or more motors connected in cascade. VI. Adjusting the frequency of the primary current. VII. Changing the number of phases of the secondary windings.

The results obtained by the use of these various methods differ widely, so that in selecting a variable speed alternating-current motor careful consideration must be given to the characteristics of the method of control in order to determine its suitability for the service. In many cases a combination of methods is required in order to produce the desired speed changes.

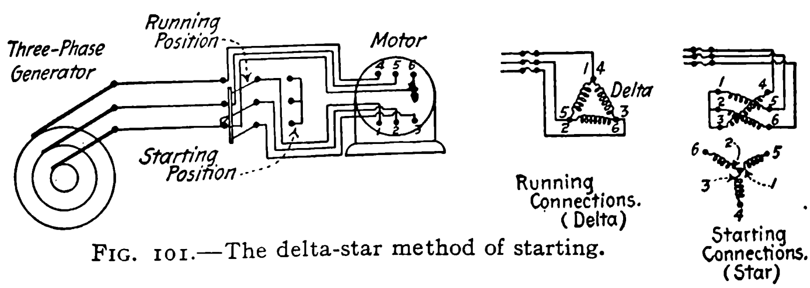


Fig. 101.—The delta-star method of starting.

219. **Speed Control of a Polyphase Motor by Adjusting the Resistance of the Secondary Circuit.**—With constant torque, the speed of the motor increases regularly as each step of the resistor is short-circuited and remains constant on any given notch. But with varying torque the motor speed varies also; that is, an alternating-current motor when operating with auxiliary resistance in the rotor circuit is properly classified as a *varying speed motor*. This method of speed control is, therefore, not suitable for service requiring several constant speeds with varying torque, such as machine-tool work, etc.

Speed control by means of adjustable secondary resistance is,

however, very useful where constant speeds are not essential, for example, in operating cranes, hoists, elevators, and dredges, and also for service in which the torque remains constant at each speed, as in driving fans, blowers, and centrifugal pumps. In service where reduced speeds are required only occasionally and where small speed variation is not objectionable, this method of control can also be used to good advantage. On account of energy loss in the resistors, the efficiency is reduced when operating at reduced speeds, this reduction being greatest at the slowest speeds. The circuits are essentially the same as for starting by varying resistance in the rotor circuit, as shown in Figs. 90 and 91.

220. With secondary speed control the rotor usually has a Y-connected winding to which is connected, in series in each phase, an external resistance, Figs. 90 and 91. By moving the adjustable arm the amount of resistance in series in each phase can be varied from a maximum to zero and the speed varied from the highest speed to the lowest speed. This form of control is in general preferable to the primary control method and is used where a large number of speeds is required and it is not necessary for the motor to run at any considerable period at reduced speed.

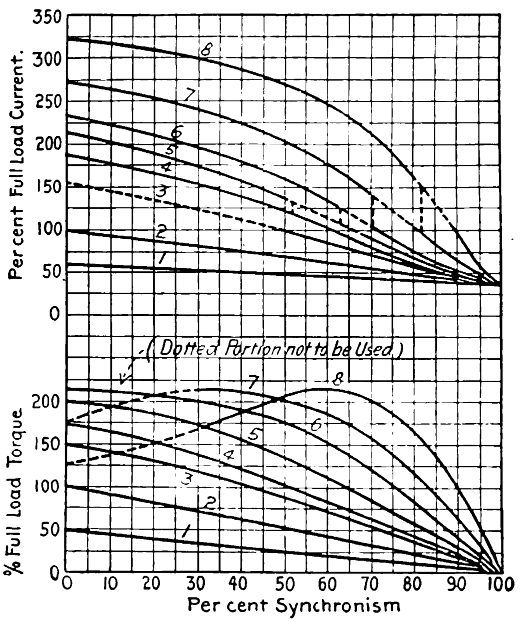


FIG. 102.—Typical current, torque, and speed curves for an induction motor with secondary speed control.

221. Speed-torque Curves of a Secondary Speed-control Induction Motor.—(See Fig. 102.) To determine the speed of such a motor on any point of the controller when operating against a given torque and to find the current taken at that speed and torque, refer to curves which show the speed, torque and current for phase-wound variable speed motors. Those of Fig. 102 are typical of ordinary capacities. For any given torque, follow along the abscissa corresponding to this value to its point of intersection with the torque curve for that particular notch of controller. Then follow up the ordinate until it intersects the current curve corresponding to the same controller notch and the value so obtained is the current taken by the motor.

Example.—Suppose it is desired to determine the current taken on the various points of the controller when starting a 25-h.p. 220-volt motor and

bringing it from rest to full speed against full-load torque—the first point (Fig. 102) at which more than full-load torque can be obtained is the third notch and following the line upward to the current curve we see that the current taken is 150 per cent. full-load current. This value drops until about 45 per cent. synchronous speed is reached, when in order to hold up the torque it is necessary to throw to the fourth notch.

The current rises correspondingly to 130 per cent. full-load, then drops until 53 per cent. synchronous speed is reached. Then the controller must be moved to the fifth notch, thence it drops until 65 per cent. synchronous speed is reached, etc.

The dotted line indicates the variation in current.

222. Speed Control of a Polyphase Motor by Adjusting the Primary Voltage.—(Fig. 103.) Adjusting the primary voltage of a motor causes speed changes that are similar to those produced by adjusting the resistance of the motor secondary. The voltage variations can be obtained by means of adjustable resistors, auto-transformers, or choke coils in series with the primary.

This method has the disadvantages of poor speed regulation, low efficiency, and unsatisfactory control, especially when the pri-

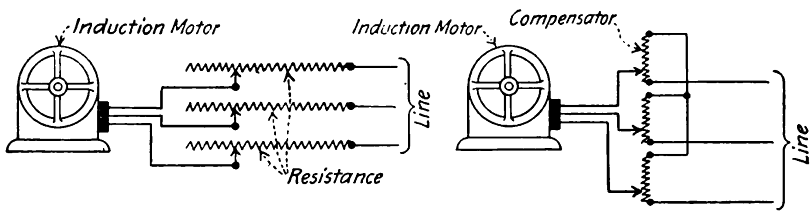


FIG. 103.—Methods of varying the voltage impressed on an induction-motor.

mary voltage is high; it is not in general commercial use. Squirrel cage induction motors are, however, almost invariably started with reduced primary voltage obtained by means of auto-transformers. Fig. 104 indicates the external appearance of a variable-resistance starter for such service.

223. Primary Speed Control.—(Fig. 103.) Where a compensator is used, contactors, connected by conductors to the stator, are arranged to slide over the compensator taps, in a manner similar to that in which the lever arm slides over the segments of a rheostat, and thereby vary the voltage impressed on the rotor. The speed regulation of a motor controlled by this method is very poor and the power factor and efficiency decrease with the speed. Where a resistance is used for varying the voltage impressed on the stator, the regulation and efficiency of the machine are not as good as when a compensator is used.

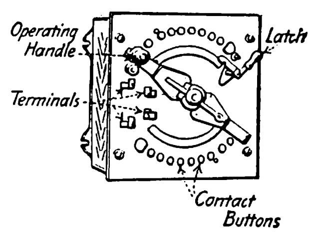


FIG. 104.—Primary resistance starter for a squirrel cage motor.

224. Speed Control of a Polyphase Motor with a Double Primary Arrangement.—The double primary motor resembles an ordinary squirrel cage induction motor in construction except that the primary is divided vertically into halves, each with separate core

and windings. One-half can be rotated around the rotor by means of a worm-screw and rack device. Fig. 105 shows this construction. When the two halves of the primary are placed so that like poles are in line, the rotor windings are subjected to maximum magnetic flux from the primary, and the motor will run with minimum slip and therefore at its maximum speed. By turning the movable half of the primary, the flux acting on each rotor bar is gradually reduced, causing increased slip and a corresponding reduction of the motor speed for a given torque.

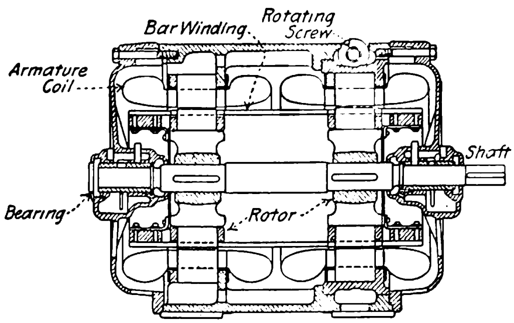


FIG. 105.—Longitudinal section of a double primary motor.

This operation is equivalent to varying the primary voltage and therefore cannot be used with advantage where constant speed with varying torque is desired. The mechanism is, however, self contained; the speed changes are effected without opening circuits; and the motor, having no brushes, operates without sparking.

225. Speed Control of a Polyphase Motor by Changing the Number of Motor Poles.—The synchronous speed of a polyphase motor is inversely proportional to the number of its poles. Thus on a 60-cycle circuit a two-pole induction motor has a synchronous speed of approximately 3,600 r.p.m., a four-pole motor 1,800 r.p.m., an eight-pole motor 900 r.p.m., etc. It is therefore possible to alter the speed of a motor by changing the number of its poles.

This can be accomplished by using two or more separate primary windings, each having a different number of poles, or by using a single winding which can be connected so as to form different numbers of poles. In general only two speeds are possible without great complication, the preferable ratio being 1 : 2. The rotor should be of the squirrel cage type as this is adapted to any number of poles, whereas the windings of a wound rotor must be reconnected for the different speeds.

With very few exceptions these motors are squirrel cage machines with special stator windings. They are designed to operate at full and half speed, the different speeds being obtained by changing the connection of the coils so as to halve or double the number of poles. Usually motors with the lower speed other than half speed require more complicated connections and necessitate bringing out a large number of leads from the motor. The motors can be designed for three or four speeds, but such will require two distinct stator windings. Obviously these motors are very special and their use is not advocated except when absolutely necessary.

The efficiency is approximately the same at each speed and the power factor which is lower at full speed than that of the normal motor is reduced very greatly at the lower speed. Also the out-

put is proportional to the speed, while the percentage slip remains approximately the same for each speed, and the starting torque per ampere varies approximately inversely as the speed.

226. **Speed control of polyphase motors by operating two or more motors connected in cascade** offers, under some conditions of service, the most convenient and economical method of speed variation. In this arrangement all the rotors are mounted on one shaft or the several shafts are rigidly connected. The primary of the first motor is connected to the line, its secondary, which must be of the phase-wound slip-ring type, to the primary of the second motor and so on. The secondary of the last motor can be either of the squirrel cage or of the phase-wound type. In practice more than two motors are rarely used. The arrangement is shown in Fig. 106.

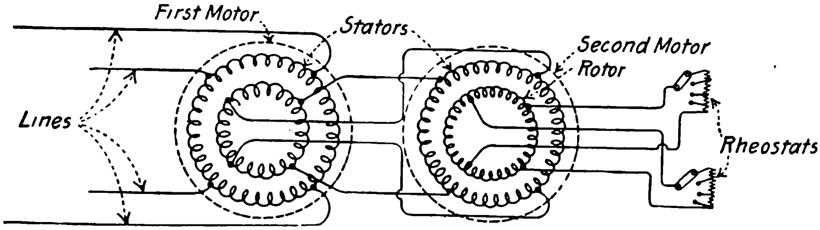


FIG. 106.—Two polyphase motors connected in cascade.

Speed changes are obtained by varying the connections of the motors, the following combinations being possible with two motors: Each motor can be operated separately at its normal speed with its primary connected to the line, the other motor running idle; the motors can be connected in cascade so that the rotors tend to start in the same direction (direct concatenation); or the motors can be connected so that the rotors tend to start in opposite directions (differential concatenation). If the first motor has 12 poles and the second 4, the following synchronous speeds can be obtained on a 25-cycle circuit.

(1) Motor *II* (4 poles) running single, 750 r.p.m.; (2) motors in differential concatenation (equivalent of 8 poles), 375 r.p.m.; (3) motor *I* (12 poles) running single, 250 r.p.m.; (4) motors in direct concatenation (equivalent of 16 poles), 187.5 r.p.m. By the use of adjustable resistance in the secondary circuits, changes from one speed to the next can be made with uniform gradations.

A great number of speed combinations are possible by the use of this method; the control is simple and safe, as few leads are required and main circuits are not opened for most of the speeds. The rotors can be made with smaller diameters than is possible with other multispeed motors, hence the flywheel effect is reduced to a minimum. In general, a cascade set is applicable where speed changes must be frequently made with high horse-power output and primary voltage, and where the speed ratios are other than 1:2.

227. **Speed Control of a Polyphase Motor by Adjusting the Frequency of the Primary Current.**—Since the synchronous speed

of an induction motor is equal to the alternations of the supply circuit divided by the number of poles in each circuit, a change in speed can be effected by changing the frequency of the circuit.

Fig. 107 shows the speed-torque and other curves of a motor when operated at 7,200, 3,600, 1,800, and 720 alternations per minute, or at 100, 50, 25, and 10 per cent. of the normal alternations. The speed-torque curves corresponding to the above alternations are *a*, *b*, *c*, and *d*. The current curves are *A*, *B*, *C*, and *D*. This figure shows that for the rated torque *T*, the current is practically constant for all speeds, but the electro-motive force varies with the alternations. Consequently, the apparent power supplied, represented by the product of the current by electro-motive force, varies with the speed of the motor, and is practically proportionate to the power developed.

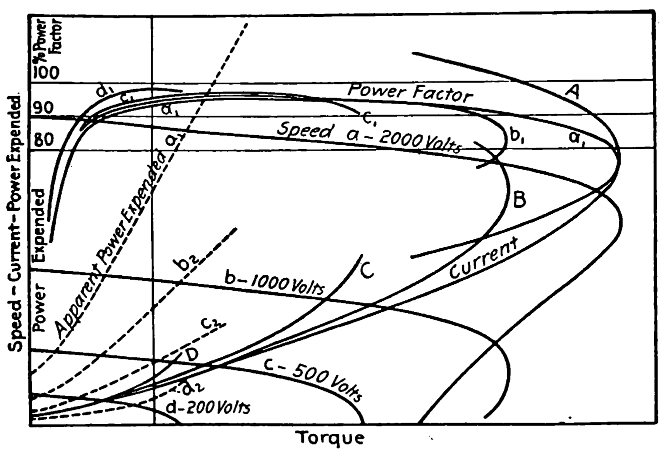


FIG. 107.—Performance curves of a polyphase induction motor with different applied frequencies and different applied electromotive forces.

In a few cases, where only one motor is operated, the generator speed can be varied. If the generator is driven by a water-wheel, its speed can be varied over a wide range, and the motor speed will also vary. If the generator field is held at practically constant strength, then the motor speed can be varied from zero to a maximum at constant torque with a practically constant current.

Another method of accomplishing this result is by the use of a frequency changer. Fig. 108 shows the arrangement. *B* and *C* are induction motors of the ordinary type; *A* is a direct-current motor directly connected to the rotor of *B*. *C* is the driving motor and *B* the frequency changer. The primary of *B* is connected to the line, its secondary to the primary of *C*. The frequency of the current delivered to *C* depends on the relation of the speed of the rotor *B* to the synchronous speed of *B*; the slower the rotation of the rotor the higher the frequency delivered to *C* and the higher the speed of *C*. The speed of the rotor *B* is controlled by adjusting the field of motor *A*. Motor *B* must be practically the same size

as C; but motor A can generally be relatively smaller, the exact size depending on the maximum and minimum frequency and the power required for motor C.

This method can be applied with special advantage where direct-current motor drive is not desirable.

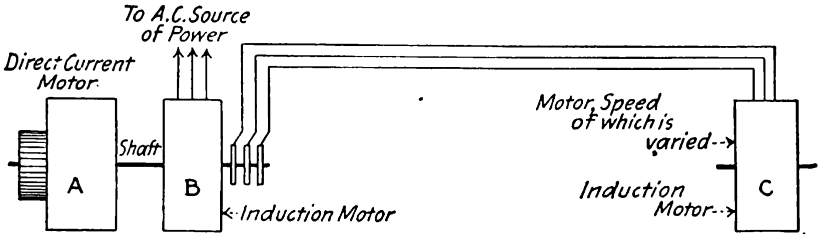


FIG. 108.—Speed adjustment by changing frequency.

228. Speed Control of a Polyphase Motor by Changing the Number of Phases of the Secondary Winding.—Phase-wound motors have in almost all cases secondaries with three-phase windings. If only one of the secondary circuits is closed the motor will run at about half speed, with very low power factor and poor efficiency. This method of speed adjustment (Fig. 109) is frequently used in experimental work, but has no extensive commercial applications.

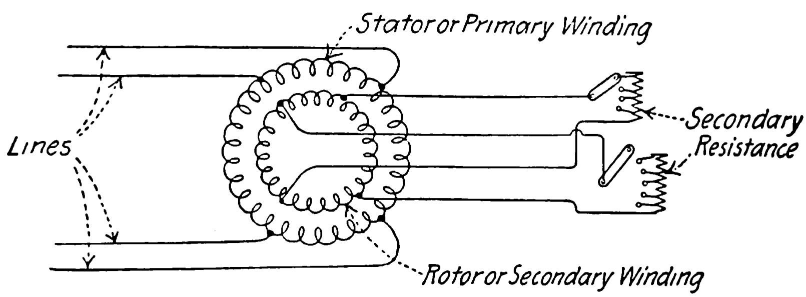


FIG. 109.—One secondary circuit closed (changing the number of phases of the secondary winding).

THE APPLICATION OF ELECTRIC MOTORS

229. Comparative Cost of Line-shaft and Individual Motor Drive for Machine Tools (*Amer. Mach.*, Sept. 26, 1912).—The most economical motor will compare favorably in first cost with line-shaft drive. Its first cost does not exceed by much that of installing line shafting, countershafting and belts. The difference is paid for in two or three years when so small an item as the power saved in friction of overhead mechanical transmission equipment alone is considered. The saving in production will pay for the difference in a very short time.

230. Direct-current Versus Alternating-current Motors.—Whether alternating-current or direct-current motors shall be

used is usually determined by the kind of energy available. If a new power plant is to be installed, however, the operating conditions may sometimes affect the choice of current. Even in this case the characteristics of the new plant should agree with those of the nearest central station in order to obtain break-down service and to operate economically with central-station energy on reduced loads. For certain applications, direct-current motors are preferable; for example, in adjustable-speed service, as in machine-tool operation, in service where frequent starts must be made with very high torque, or in reversing service, as in the operation of cranes, hoists, etc.

The voltage of alternating-current circuits can be so readily transformed up or down that such energy is more economical for distribution over considerable areas. For plants extending over a considerable area or distributing energy to distances, say, of one-fourth mile or more, alternating current is nearly always more economical. In order to utilize alternating-current for distribution when direct-current motors are preferable, the installation of rotary converters or motor generators for changing from the one kind of current to the other is sometimes warranted.

The question of protecting motors from dust and refuse sometimes determines the system that must be employed. Where there is any possibility of injury from the accumulation of dirt or dust in motors, semi-enclosing or totally enclosing covers are essential on all motors having sliding contacts. Totally enclosing covers stop the ventilation of the motor and therefore increase the temperature for a given load, or decrease the capacity for a given temperature. Gritty dust, as in cement mills, causes rapid wear on the commutators, and totally enclosing covers are recommended when direct-current motors are used in such locations. Squirrel cage induction motors, having no sliding contacts, are preferable for all service of this nature.

The torque, or turning moment, sometimes determines which class of motors to use. According to its design, an alternating-current induction motor will start with a torque ranging from one to three or more times the torque required to develop full-load at rated speed, and will stop, or pull out, with a torque ranging from two to four times its full-load torque. Higher relative starting torque can be obtained by the use of larger alternating-current motors, but in some cases the more practical way is to employ direct-current motors.

231. Speed Classifications of Electric Motors.—The electric motor may assume practically an infinite number of different forms and can be applied to an almost unlimited number of uses. Each motor, however, possesses certain inherent speed characteristics by means of which it can be classified in one of several groups. The following classification is that which was adopted by the American Association of Electric Motor Manufacturers, January, 1909:

(a) *Constant-speed Motors.*—In which the speed is either constant or does not materially vary, such as synchronous motors, induction motors with small slip, ordinary direct-current shunt-wound motors and direct-current compound-wound motors, the

no-load speed of which is not more than 20 per cent. higher than the full-load speed.

(b) *Multispeed Motors.*—Two-speed, three-speed, etc., motors which can be operated at any one of several distinct speeds, these speeds being practically independent of the load, such as direct-current motors with two armature windings and induction motors with primary windings capable of being grouped so as to form different numbers of poles.

(c) *Adjustable-speed Motors.*—(1) Shunt-wound motors in which the speed can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load; such as motors designed for a considerable range of speed by field variation.

(2) Compound-wound motors in which the speed can be varied gradually over a considerable range as in (1), and when once adjusted varies with the load similar to compound-wound constant-speed motors or varying-speed motors, depending upon the percentage of compounding.

(d) *Varying-speed Motors.*—Motors in which the speed varies with the load, decreasing when the load increases, such as series motors and heavily compounded motors. Examples of heavily compounded motors are those designed for bending roll and mill service, in which a shunt winding is provided only to limit the light-load operating speed.

232. **Determining the Speed Required of a Motor for a Given Application** (*Earl D. Jackson*, *Engineering Magazine*, September, 1911).—Ascertain accurately the desired speed or speeds of the machine to be driven, and the maximum horse-power as well as the average horse-power required. The speed or speeds of the driven machine may be ascertained by tests with an experimental motor, or from data furnished by the builder of the machine. Often individual motor drive is to replace steam or group drive, in which cases speeds are easily determined.

233. **The horse-power required of the motor** (*Earl D. Jackson*) should be determined accurately. The purchaser may rent an experimental motor and ascertain the power required. This is probably the most satisfactory way. Group drive generally requires that this be done, as the amount of power required for a group of machines is problematical. Note that from the input to the test motor, as measured with a wattmeter, or with a voltmeter and ammeter, should be subtracted the test-motor losses, as the motor to be purchased is rated on horse-power output or brake-horse-power. Money spent in the accurate determination of the power required is wisely expended.

Machine-tool builders, and motor manufacturers, are often requested to supply the information as to how large a motor should be. The machine-tool builder often overestimates the horse-power required to be on the safe side. The result is that the motors run at one-quarter to one-half load at greatly reduced efficiency. The electrical losses, and interest and depreciation on the unnecessary extra investment may amount to considerable in a large installation.

234. **Open Versus Enclosed Motors.**—The metal covers of closed motors reduce the efficiency and capacity of the motor by preventing free circulation of air around the active elements of the motor. Working conditions usually determine whether it is possible to use the open motor, which is, of course, the desirable practice, or whether the presence of excessive dust renders it necessary to enclose the moving parts of the motor partially or completely. The partially or semi-enclosed motor should not be placed in a concealed position because it will then be neglected. Perforated covers and wire screens clog up by dust and dirt, and a semi-enclosed motor becomes, virtually, a totally enclosed motor with a semi-enclosed rating and consequent trouble.

235. **Application of Vertical Motors.**—Vertical motors are recommended only when the nature of the drive renders it apparent that they possess great advantages over motors of the standard or horizontal type. Vertical motors are, in general, inclined to be troublesome and require greater attention. They are not generally kept in stock. The motor and repair parts must be replaced from factory stock and a delay in shipment usually results.

236. **The rating of motors** is determined by the continuity of operation, which must accordingly be considered in making a selection. The heating of the machine due to the passage of electric current through it largely determines the rating. If too great a load is imposed the motor will become excessively hot and the insulation will probably be injured. Obviously, a motor can be rated higher for intermittent service than for continuous service; conversely, a motor rated for intermittent service must not be used at the same rating for continuous service. In any service a motor can nearly always deliver more than its standard continuous rated output for short periods only, with intervening periods of rest. This fact is often overlooked, and motors larger than necessary are accordingly selected.

237. **Factors Affecting the Selection of Small Motors** (*Westinghouse Publication*). *Alternating-current, Single-phase Motors.*—Single-phase motors should be selected with starting torque that will bring the machine promptly up to speed. Allowance must be made for reduced voltage of circuits, since the starting torque varies as the square of the voltage. On account of too small wiring or insufficient transformer capacity, the voltage of many such circuits drops considerably at times. While the motor is starting, the voltage may drop to possibly 80 per cent. of its rated value at which the starting torque of the motor is only approximately 64 per cent. of the torque at full voltage. For these reasons, motors to drive machines from the ordinary lighting circuits should be selected for the worst probable starting conditions. Under especially severe starting conditions, centrifugal clutches are advisable on single-phase motors. The clutch operates automatically after the motor has attained nearly full speed, thus minimizing both the amount and the duration of the starting current.

The maximum turning effort, or torque, while the motor is running must also be ample for the worst load conditions to which

the machine will probably be subjected, and with voltage at least 10 per cent. below rated voltage.

Direct-current Motors.—The operating characteristics of direct-current motors depend very largely on the field windings. The following comparison applies to shunt- compound- and series-wound motors of the same rating and efficiency, hence the same rated full-load current input. *Shunt-wound motors* take starting current in direct proportion to the starting effort or torque required, and the speed while operating remains practically constant at all loads. Such motors are most generally applicable unless the starting conditions are too severe.

Compound-wound motors will develop higher starting and maximum torques with the same current input than shunt-wound motors, but the speed while operating varies more widely with the load. They should be applied where high starting effort with low current is desired, and where some change of speed with load is not objectionable. Also on circuits with fluctuating voltage the series field winding of such motors helps to steady the current and speed.

Series-wound motors develop higher starting and maximum torques with a given current input than either shunt or compound motors; but while operating, the speed varies widely with the load, increasing to a dangerously high speed at no-load. Series motors are applicable where very heavy torque must be developed, either while starting or operating, and where varying speed with varying load is not objectionable. Series motors must not be belted or applied where the load may become very light, since if the belt should come off, or the load be removed in any other way, the speed would become excessive.

238. **The standard direct-current motor voltage** practically standardized for factory use is 220 volts. This voltage is both economically and operatively superior for direct-current motor systems to that of 110 volts sometimes employed.

239. Types of Direct-current Motors for Different Speed Requirements (*Engineering Magazine*, September, 1911)

Requirement	Type of motor
Approximately constant speed, no-load to full-load.	Shunt motor. Shunt-commutating pole motor.
Semi-constant speed, no-load to full-load.	Compound motor.
Adjustable speed, remaining approximately constant for one adjustment, no-load to full-load.	Shunt motor, with adjustable field resistance. Shunt-commutating pole motor with adjustable field resistance.
Adjustable speed, semi-constant for one adjustment, no-load to full-load.	Compound motor, with adjustable shunt field resistance.
Varying speed, varying with the load.	Series motor. Series-commutating pole motor.

240. Characteristics of Direct-current Motors and Their Fitness for Different Applications.—This subject is treated, in addition to the matter in the following paragraphs, in several paragraphs in this section starting with 249.

241. Induction-motor Applications (*A. M Dudley, Electric Journal*, July, 1908)

Squirrel cage		Phase-wound	
Constant speed	Variable speed	Constant speed	Variable speed
1. Motor-generator sets.	1. Starting motors.	1. Flour mills.	1. Hoists and winches.
2. Pumps.........	2. Crane motors.	2. Paper, machinery, pulp grinders, beaters.	2. Cranes.
3. Blowers........	3. Fly-wheel service, punches, shears, etc.	3. Belt conveyors.	3. Elevators.
4. Line-shaft drive.	4. Sugar centrifugals.	4. Wood planers.	4. Fly-wheel motor-generator sets.
5. Cement machinery.	5. Laundry extractors.	5. Air compressors.	5. Steel-mill machinery charging machines, hoists.
6. Wood-working machinery (except planers).	6. Brake motors.	6. Line shafting..	6. Coal and ore unloaders.
7. Cotton-mill machinery.	7. Cross-head motors.	7. Driving wheel lathes.	7. Dredging machinery.
8. Paper machinery, calendars, Jordan engines.	8. Valve motors.	....	8. Shovels.
9. Concrete mixers.	....	....	9. Mine haulage.

242. Squirrel Cage Induction-motor Applications for Constant-speed Service (*A. M. Dudley, Elec. Jour.*, July, 1908). *Motor-generator Sets.*—Small starting torque is required and good speed regulation, which characteristics are preeminently met by a squirrel cage motor with very low resistance in the secondary rings. A fair specification on a large set is that it shall start on 30 to 40 per cent. of full voltage, and draw current not in excess of 1¼ times full-load current.

Pumps.—With a centrifugal pump, decreasing the head pumped against increases the load on the motor. This type of pump will raise considerably more than four-thirds the amount of water 30 ft. that it will 40 ft., with the result that the motor is overloaded if it is designed for 40 ft. head. In this the centrifugal pump is exactly opposite to the plunger or reciprocating pump, which, being positive in its action, increases its load with increase of head and vice versa. (In some modern types of centrifugal pump the load decreases with decrease of head after reaching the maximum load corresponding to the head for which the pump is designed.

Blowers.—*Rotary blowers*, except positive blowers, have a char-

acteristic similar to centrifugal pumps, in that the load varies with the amount of air delivered and becomes less as the pressure against which the blower is working increases. That is to say, the maximum load which could be put on a motor driving a blower of this nature would be to take away all delivery pipes and let the blower exhaust into the open air.

Line Shafting.—Squirrel cage motors are used very successfully for driving line shafting where the idle belts are run on loose pulleys, in this way keeping down the starting torque.

Cement Mills.—The possibility of entirely covering the bearings and the absence of all moving contacts make the squirrel cage motor successful where the more complicated construction and moving contact surfaces of the wound secondary motor or the direct-current machine are damaged by accumulation of dust. In starting up a tube mill it must be rotated through nearly 90 per cent. before the charge of pebbles and cement begins to roll. This makes the starting condition severe and a motor should have a starting torque of not less than twice full-load torque to do the work.

Wood-working Machinery.—On account of high friction and great inertia, the starting torque is sometimes so high and of so long duration (30 sec. to 1 min.) that it is sometimes better to apply a wound secondary motor.

Paper Machinery.—If calendars are driven with a constant-speed motor, it is necessary to make some provision either by mechanical speed-changing devices or a small auxiliary motor for securing a slow threading speed.

243. **Squirrel Cage Variable Speed Motor Applications.**—These motors in general have high-resistance end rings, high slip and high starting torque. The torque increases automatically as the speed decreases. In these general respects they resemble a direct-current series motor and are in fact fitted for the same class of work, with the added advantage that they have a limiting speed and cannot run away under light load.

Flywheel Service.—In driving tools which are used with fly-wheels, such as punches, shears, straightening rolls and the like, the usefulness of high slip comes in, as if the fly-wheel is to give up its energy, it is obliged to slow down in speed when the load comes on. A motor with good regulation and low slip would try to run at constant speed, carrying the flywheel and load as well, but the motor in question "lies down" and allows the flywheel to carry the peak load, speeding up again when the peak has passed.

In sugar centrifugals is an application where the sole purpose of the motor is to accelerate the load to full speed, in say 30 sec., where it is allowed to run 1 min. and then shut down to repeat the cycle a minute later. The centrifugal consists of a cylindrical basket with perforated walls and mounted around a vertical shaft as an axis. The same principle is used in laundry extractors where the wet linen is placed in a similarly perforated basket and the water whirled out by centrifugal force.

244. **Applications of Constant-speed Motors with Phase-wound Secondaries.**—There are classes of service which require

a heavy starting torque combined with close speed regulation after the motor is up to speed. These requirements are exactly satisfied by a motor with a phase-wound secondary. The secondary winding itself has a very low resistance, which results in a small "slip," high running efficiency, power factor and good regulation when the secondary is short-circuited. The insertion of external resistance enables the motor to develop maximum torque at the start with a moderate starting current.

Flour Mills.—The number of line shafts, belts and gears in flour mills makes a very heavy starting condition and the nature of the product and its quality demand absolute speed within a few revolutions per minute. The best solution is the phase-wound rotor.

Other Examples.—There is another class of machinery which is not so exacting about regulation but which has the same feature of heavy starting and runs continuously after once up to speed. Under this head come most of the applications of this type of motor. They are, paper-pulp grinders, which, on account of the inertia of the grindstones, are hard to start; pulp beaters, belt conveyors, which may be required to start when full of coal; rock or cement crushers; air compressors, which have a high starting friction because of the construction and the number of parts; line shafting where the belts run for the most part on the working pulleys and are therefore heavy to start. Under the best possible conditions, if line shafting is employed, the loss of power from this source alone, due to friction, is 25 per cent. to 30 per cent. and may run up to 40 or 50 per cent. This is a strong argument for individual drive of machines wherever practicable.

245. Application of Motors with Phase-wound Secondaries for Variable-speed Service.—The application, which is typical of this class, is found in hoist and crane service. Motors for this work are designed for intermittent operation and given a nominal rating based upon the horse-power which they will develop for ½ hr. with a temperature rise of 40 deg. cent. They never operate for as long a period as 30 min. continuously and they are called upon at times to develop a torque greatly in excess of their nominal rating. For these reasons motors of this class should never be applied on a horse-power basis, but always on a torque basis. Since torque is the main consideration and the service is intermittent these motors are usually wound for the maximum torque which they will develop and given a nominal rating based upon one-third to one-half of this torque. Double-drum hoists, hoisting in balance, and large mine haulage propositions in general require a motor rated on a different basis. For this service the motor should have the necessary maximum torque, and be able to develop for about two or three hours, with a safe rise in temperature, a horse-power equivalent to the square root of the mean square requirement of the hoisting cycle. These are only general rules and the most careful consideration should be given in each individual case to secure a motor which will perform the work satisfactorily.

Coal and Ore Unloading Machinery. Dredges. Power-shovels.—Owing to the complication of the cycle of operation there is more

difficulty in providing a motor for this apparatus than in the case of a plain hoist. Usually the number of cycles per hour given is the maximum which the apparatus can develop and in practice it will not be possible to operate at so high a speed. This in itself is somewhat of a factor of safety, though it is not one that can be relied upon, as the test for acceptance is ordinarily made at the contract number of operations per hour.

The most impressive application of motors of this class, and perhaps in the operation of any electrical apparatus, is the fly-wheel motor-generator set for hoisting or heavy reversing roll service in steel mills. Service of this nature is extremely fluctuating in its requirements, having very great peaks one instant and almost nothing the next.

246. Operating Speeds of Various Machine Tools

Saws, circular (wood)	9,000 ft. per min. at rim
Saws, band (wood)	4,000 ft. per min. at rim
Saws, band (hot iron and steel)	200–300 ft. per min. at rim
Grindstones	800 ft. per min. at rim
Emery wheels	5,000 ft. per min. at rim
Drills (for wrought iron)	12 ft. per min. outer edge
Drills (for cast-iron)	8 ft. per min. outer edge
Milling cutters (for brass)	120 ft. per min. outer edge
Milling cutters (for cast-iron)	60 ft. per min. outer edge
Milling cutters (for wrought iron)	50 ft. per min. outer edge
Milling cutters (wrought steel)	35 ft. per min. outer edge
Screw cutting (gun metal, etc.)	30 ft. per min. at circum.
Screw cutting (steel)	8 ft. per min. at circum.
Boring (cast-iron)	10 ft. per min. at circum.
Sawing (wood)	1,500 ft. per min. at circum.
Sawing (brass)	70 ft. per min. at circum.
Sawing (gun-metal)	30 ft. per min. at circum.
Sawing (steel)	25 ft. per min. at circum.
Sawing (wrought iron)	30 ft. per min. at circum.
Sawing (cast-iron)	20 ft. per min. at circum.

247. Size of Motors to Drive Machine Tools

Machine	Size	H.p. of motor
Engine lathes, 14 to 48 in. swing	Light duty	2 to 7½
	Heavy duty	5 to 20
Vertical boring rolls	20 in.	5
	100 in.	15
	16 ft.	30
Radial drills	4 to 10 ft.	3 to 7½
Upright drills	15 to 50 ft.	½ to 3
Milling machines	Small	3
	Large	15
Planers	24×24 in.	5 to 7½
	56×56 in.	15 to 25
	14×12 ft.	75 main motor 12 rail motor
Shapers	14 to 36 in.	3 to 7½
Slotters	10 to 30 in.	3 to 15
Cold saws	1 to 3 ft.	2 to 10
Grinders		5 to 15

248. Motor-driven Wood-working Machinery.—Alternating-current, squirrel cage, constant-speed induction motors form the most suitable drive for the majority of wood-working machines.

In some few machines, as in "hogs" for reducing slabs to kindling, high flywheel effect makes starting difficult, and motors with phase-wound rotors and external resistance are preferable. For machines requiring adjustable speed, such as certain types of wood lathes, direct-current shunt-wound motors give the best results because of the greater range of speeds possible.

249. **Individual Motor Drive and Group Drive for Wood-working Machinery.**—Individual motor drive should be used for single machines that are operated more or less irregularly but at their full capacity. This applies to most wood-working machines. Group drive is satisfactory for machines used frequently but not simultaneously. Thus an emery wheel, knife grinder, carving machine, cabinet saw and disc sander can all be run by one motor, which can have a capacity of considerably less than the aggregate rating of the machines it is used to drive.

250. Size Motors Required to Drive Wood-working Tools

Machine	Size	Motor h.p.
Jointers	Small	2
	Large	5 to 7½
Inside molders	8×4	15
	15×6	20 to 30
Outside molders	4×4	5
	8×4	10
	14×5	20
Mortising machines		3 to 5
Planers, matchers, and molders	9× 6	30
	30×12	40
Surfacers	Small, slow feed	5
	Large, rapid feed	30
Belt sanders		3 to 5
Column sanders		3
Disc sanders		3
Drum sanders	16-in. drum	3
	42-in. drum	10
	60-in. drum	20
	80-in. drum	30
	102-in. drum	40
Spindle sanders		3
Band saws	Small	3
	Large	20
Band re-saws	8×24	15
	28×36	40
Circular saws, single cut off	14 in.	3
	36 in.	5
	60 in.	60
Circular rip saw	14 in.	10
	36 in.	15
Timber sizers		30 to 50
Tenonizing machines	Small	3 to 5
	Large	10 to 15

251. **Motor-driven Pumps** (*Westinghouse Diary*).—Either direct-current or alternating-current motors are satisfactory. (See 254.) For most cases shunt-wound direct-current and squirrel cage alternating-current motors are suitable; but when the starting conditions are severe, as when the pump must be started against a full discharge pipe, compound-wound direct-current and phase-wound alternating-current motors are preferable.

252. Power Required for Printing Machinery
(W. O. Webber, "Power")

		h. p.
	30 in. by 52 in., 2 rev., No. 8 Cottrell press, 19 impressions per min.	1.19
	27 in. by 41 in., No. 20 Adams press, 16 impressions per min.	0.68
	32 in. by 54 in., Huber perfecting press	2.44
	43 in. by 64 in., Huber perfecting press, automatic feed	5.55
	27 in. by 41 in., No. 4 Adams job press	0.43
	26 in. by 40 in., No. 2 Adams job press	0.34
	32 in. by 54 in., No. 1 Potter cylinder roller press	0.50
	26 in., No. 1 Hoe perfecting press	5.41
	Web paper-wetting machine	0.52
News-paper presses	One 10-page web perfecting press, 12,000 per hr.	15.39
	One 10-page web perfecting press, 24,000 per hr.	31.00
	One 12-page web perfecting press, 12,000 per hr.	20.45
	One 12-page web perfecting press, 24,000 per hr.	29.56
	One 32-page web perfecting press, 12,000 per hr.	28.73
Calico printing machin'y, 100 yard goods per min.	One 19-cylinder, soaper and dryer, full, 110 r.p.m.	3.97
	One cutting machine, full, 65 r.p.m.	2.77
	One set drying cans to cutting machine, full, 110 r.p.m.	2.33
	One back starcher, 3 wide machines, full, 115 r.p.m.	4.24
	One indigo skying machine, 5 vats all working full, 64 r.p.m.	4.78
	One 40-in., 5-roll calender, working full, 234 r.p.m.	9.80
	One single-color printing machine	10.60

253. Power Required to Drive Printing Presses
(Walter Scott and Co. specifications[1])

	Mach. No.	Size of bed in.	Imp. per hour	Rev. of shaft per imp.	h.p. motor
Class C, newspaper drum cylinder.	5	29 × 42	2,000	5	2
	6	33 × 47	1,800	5	2.5
	7	37 × 51	1,600	5	3
Class D, job news drum cylinder.	1	17 × 22	2,800	4	1.5
	3	24 × 29	2,400	5.09	2
	4	26 × 34	2,200	5.07	2.5
	5	29 × 42	2,000	5	2.5
	6	32 × 47	1,800	4.96	3
Class E, high-speed drum	2	20 × 25	3,600	6	2
	3	23 × 31	3,200	6.52	2.5
	4	26 × 36	2,850	7.56	3
	5	29 × 42	2,600	8.08	3.5
2-roller two rev. high-speed.	4	26 × 36	2,800	6.8	2.5
	5	29 × 42	2,600	7	3
4-roller two rev. high-speed.	4	27.5 × 36	2,600	7.4	3
	5	30.5 × 42	2,400	7.8	3.5
	6	35 × 46	2,200	8.06	4
	7	38 × 48	2,100	8.43	4.5
	8	41.5 × 52	2,000	8.81	5
	9	45 × 56	1,900	9.37	5.5
	10	48.5 × 62	1,800	9.75	6
	11	50 × 66	1,700	9.75	6

[1] Walter Scott and Co. recommend 1 h.p. more than is called for in each case, as this gives a liberal margin for coolness in running and reserve power for special work.

254. Power Required for Pumping.—The size of motor required for operating a pump can be roughly determined by the following formula:

$$\text{h.p.} = \frac{g.p.m. \times H}{2{,}000}$$

where $g.p.m.$ is the gallons pumped per minute, and H is the total vertical lift in feet. This formula neglects friction head and assumes an efficiency of about 50 per cent. for the pumping unit. The following formula is exact for fresh water:

$$\text{h.p.} = \frac{g.p.m. \times (H+F)}{3{,}960 \times E}$$

where F is the friction head and E the efficiency of the pump expressed in hundredths. For sea water, the result should be multiplied by 1.026.

INSTALLATION OF MOTORS AND GENERATORS

255. Brief of Underwriters' Rules Covering the Installation of Generators (*Factory Mutual Fire Insurance Co's. Handbook*).—Generators should be located in clean, dry places, away from combustible materials; and a light location rather than a dark one is always preferable. It is not desirable to place them in the work-rooms of a plant where combustible material abounds, as in the ordinary textile mill, though they may sometimes be so located if properly cut off from the main room by a dust-tight plank partition. A location suitable for a first-class steam engine is none too good for a generator.

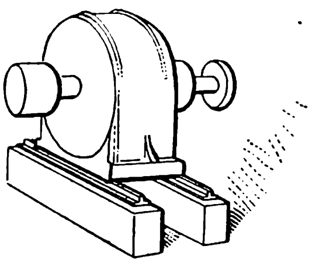


FIG. 110.—Machine mounted on two timbers.

A solid foundation is necessary for smooth running. Where a generator or motor must be mounted on timbers, two parallel timbers, as shown in Fig. 110, are preferable to a four-sided framework, which encloses a place under the machine that is difficult to keep clean.

256. Brief of Underwriters' Rules Covering Dynamo Wiring (*Wiring Rules of the Factory Mutual Fire Insurance Companies*).—Since there is generally a considerable number of wires brought close together in this room, particularly in the vicinity of the switchboard, the use of a "slow-burning" insulation is of great importance. As automatic sprinkler protection is not always advisable in dynamo rooms, the necessity for reducing as far as possible the chances of a fire at this point is at once evident. The desirability of fireproof construction throughout the dynamo room is especially emphasized.

Special care should be exercised in rigidly supporting and thoroughly insulating the wires from generator to switchboard, as the main cutouts are usually on the switchboard and a short-circuit between these wires would, therefore, be likely to burn out the armature.

257. Brief of Underwriters' Rules Covering the Installation of Motors (*Factory Mutual Fire Insurance Co's. Handbook*).—The use of voltages above 550 in rooms where manufacturing processes are being carried on will be approved only when every practicable safeguard has been provided. Plans for such installations should be submitted to the Inspection Department before work on them is begun.

Direct-current motors and alternating-current motors with brushes should be so located or enclosed, especially in dusty or linty places, that inflammable material or flyings cannot accumulate around them and become ignited by serious sparking at the brushes. Similar protection should also be provided in wet places, as most electrical machinery is injured by continued exposure to moisture.

Alternating-current induction motors of the type without brushes can be safely located in almost any part of a textile plant without being enclosed, being generally no more dangerous than any other piece of machinery running at the same speed.

For light work, direct-current motors which have all of the working parts enclosed in an iron case are on the market, and these "enclosed" motors may be treated in the same way as induction motors without brushes.

Where an enclosure around the whole motor is provided, it should include the starting rheostat or auto-starter, as well as the main switch and fuses or circuit-breaker, and should, if possible, be of such a size as will permit the attendant to enter it and easily get at any part of the apparatus. It should preferably be made largely of glass, so as to keep the motor in full view of the attendants, thus promoting cleanliness and making it possible to quickly discover any derangement. It should also be thoroughly ventilated, in order to prevent undue heating of the electrical machinery.

Where the use of a motor is permitted in a dusty or linty place without being enclosed, or if the enclosure provided for it is too small to include anything else, the rheostat or auto-starter and the main switch and fuses or circuit-breaker should be placed in a dust-tight cabinet of approved construction. Similarly, in wet places, these accessories should be protected from moisture in a cabinet which is thoroughly water-tight.

258. Commonwealth Edison Company Rules for Motor Wiring (*Commonwealth Edison Co. Handbook*).—Wiring for motors should be so arranged that the current used for power purposes may be metered separately from that used for lighting. Wiring for elevators should also be arranged so that current used on elevators may be metered separately from that used for other power. All motors larger than 1 h.p. must be wound for 220 volts, and it is preferred that motors of $\frac{3}{4}$ h.p. and larger be so wound.

No motors larger than 5 h.p. will be supplied on single-phase system, except by special permission, given by the Inspection Department of the Company in each case. Motors of 5 h.p. and larger will be supplied on the three-phase system at 60 cycles, 220 volts, where three-phase current is available. No motor will be connected which requires more than three times full-load current in starting without load.

259. Foundations are necessary (*Practical Electricity*) to support and maintain in alignment generators and other electrical machines of any considerable size. Foundations are made of masonry. Brick or stone set in mortar (preferably cement mortar) will do, but concrete is almost universally used because it is usually the cheaper. A 1 : 3 : 6 (1 part cement, 3 parts crushed stone or gravel and 6 parts sand by bulk) or even a 1 : 3 : 7 mixture of con-

crete will give excellent results. Brick or stone for foundations can be set in a 1 part cement and 3 parts sand mortar.

260. **The size of a foundation** is determined by the size of the machine supported and by the stresses imposed by the machine. The area of base of any foundation must be great enough that its weight and the weight of the machine supported will not cause it to sink into the soil. The bearing power of soils is given in Table **260A.** Where a machine is not subjected to any external forces, that is, where it is self-contained, the only requirement of the foundation (provided the machine is not one that vibrates excessively) is to keep it from sinking into the ground and the lightest possible foundation that will do this will be satisfactory. Therefore motor-generators and rotary converters do not require heavy foundations. Machines that are driven by or drive external apparatus require foundations heavy enough to resist the tendency of the external apparatus to tip or to displace the foundation. No rule can be given for determining the proper weight for a foundation, in such a case. However, with a solid foundation, it is usually true that if the foundation is large enough to include all of the foundation bolts of the machine and to extend to good bottom, it will be sufficiently heavy. Experience is required to enable one to design the lightest possible foundation that will do, so it is well for the beginner to be sure that his foundation is heavy enough.

260A. Bearing Power of Soils (*Standard Handbook*)

Soil	Tons per sq. ft.	Remarks
Good solid natural earth........	4	New York building laws.
Pure clay, 15 ft. thick, no admixture of foreign substances except gravel........................	1.75	Chicago building ordinances.
Dry sand, 15 ft. thick, no admixture of foreign substances......	2	Chicago building ordinances.
Clay and sand mixed...........	1.5	Chicago building ordinances.
Hard rock on native bed.......	250	Richey.
Ledge rock....................	36	Richey.
Hard-pan......................	8	Richey.
Gravel........................	5	Richey.
Clean sand....................	4	Richey.
Dry clay......................	3	Richey.
Wet clay......................	2	Richey.
Loam..........................	1	Richey.

260B. Foundations for machinery should be entirely separate from those of the building (*Standard Handbook*). Not only must the foundations be stable, but in some locations it is particularly desirable that no vibrations be transmitted to adjoining rooms and buildings. A loose or sandy soil does not transmit such vibrations readily, but firm earth or rock transmits them almost perfectly. Sand, wool, hair-felt, mineral wool and asphaltum concrete are some of the materials used to prevent this. The excavation for the foundation is made from 2 to 3 ft. deeper and 2 or 3 ft. wider on all sides than the foundation, and the sand, or whatever material is used, occupies this extra space.

260C. A templet (Fig. 111) giving the location of all bolts to be used in holding the machine in place should be furnished, and the bolts may be run inside of iron pipes having an internal diameter a little greater than the diameter of the bolt. This allows some play to the bolt and is found very convenient for the final alignment of the machine. (See Fig. 112.) The bolts are sometimes cast in solid. Templets for foundation bolts can be made from $\frac{7}{8}$-in. boards. The bolts are supported in the templet while the concrete is being formed. See Fig. 111 for an example of a simple templet.

261. Foundation bolts are usually mild steel rods, threaded for nuts on both ends, of such diameter that they will readily pass through the holes in the machine bed-plates. For small machines, ordinary machine bolts will do. Bolts should always extend nearly to the bottom of the foundation. (See Fig. 112.)

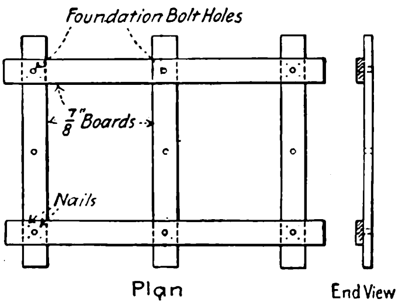


FIG. 111.—Simple foundation templet.

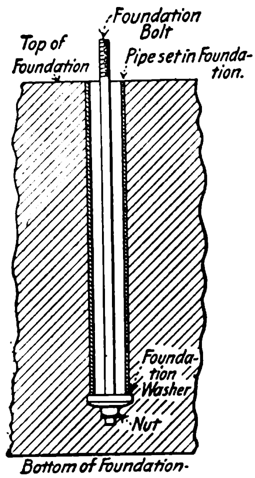
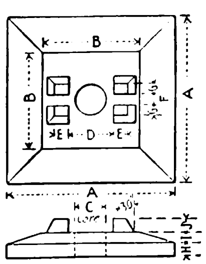


FIG. 112.—Bolt set in foundation.

262. Foundation washers are used on the lower ends of the bolts to retain them in the foundation. (See Fig. 112.) Ordinary round building washers, pieces of steel plate with holes punched in their centers, pieces of angle iron or old rails are sometimes used for foundation washers. But the form of cast-iron washer shown in Fig. 113 is better.



Diam. Bolt	Weight	A	B	C	D	E	F	G	H	I	J
$\frac{7}{8}$"	8 lbs.	6	$3\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{2}$
1"	15	8	$4\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{1}{2}$
$1\frac{1}{4}$"	30	10	$4\frac{1}{2}$	$1\frac{5}{8}$	$2\frac{1}{8}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{1}{2}$
$1\frac{1}{2}$"	45	12	$5\frac{1}{2}$	$1\frac{7}{8}$	$2\frac{1}{2}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{1}{2}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{1}{2}$
$1\frac{3}{4}$"	60	14	$5\frac{1}{2}$	$2\frac{1}{8}$	$2\frac{7}{8}$	1	1	$\frac{5}{8}$	1	$\frac{1}{2}$	$\frac{1}{2}$
2"	100	16	6	$2\frac{3}{8}$	$3\frac{1}{4}$	$1\frac{1}{8}$	1	$\frac{5}{8}$	$1\frac{1}{8}$	$\frac{7}{8}$	$\frac{1}{2}$
$2\frac{1}{4}$"	135	18	7	$2\frac{5}{8}$	$3\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{1}{8}$	$\frac{3}{4}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{2}$
$2\frac{1}{2}$"	154	20	9	$2\frac{7}{8}$	4	$1\frac{1}{4}$	$1\frac{1}{8}$	1	1	1	$\frac{1}{2}$

FIG. 113.—Dimensions of foundation washers.

263. Foundation pockets are provided in foundations where it is thought desirable to have the bolts removable. A pocket is a hole in the side of a foundation arranged so that the nut on the lower end of a foundation bolt can be reached. (See Fig. 114.) Ordinarily

foundations are not pocketed. The bolts are cast in solid. If bolts are removable it is not necessary to raise the bed-plate of a machine up over them to mount it. The bed-plate is shifted into position and then the bolts are dropped in. Washers similar to that of Fig. 115, which have a pocket for the nut, are preferable for pocketed foundations.

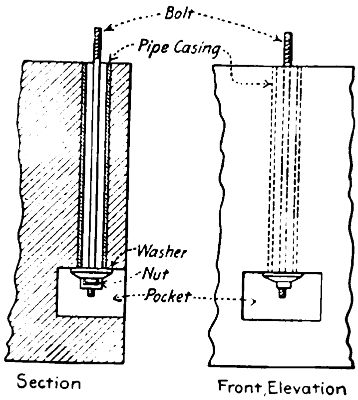


FIG. 114.—Foundation pocket.

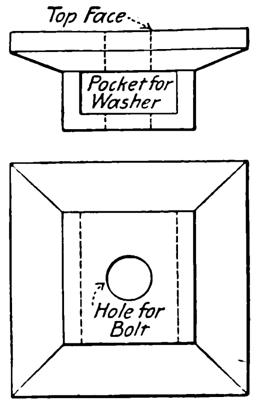


FIG. 115.—Foundation washer with pocket for nut.

264. Foundation Design.—Where feasible, the design of Fig. 116 should be used, which is as simple as can be laid out. The form for such a foundation consists of a substantial box having no bottom. Where the earth is self-sustaining such a foundation can be made by throwing the concrete into a hole of proper proportions (Fig. 117). The sides of the hole constitute the form. Founda-

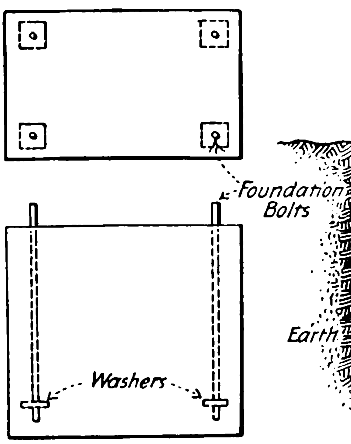


FIG. 116.—Simple foundation.

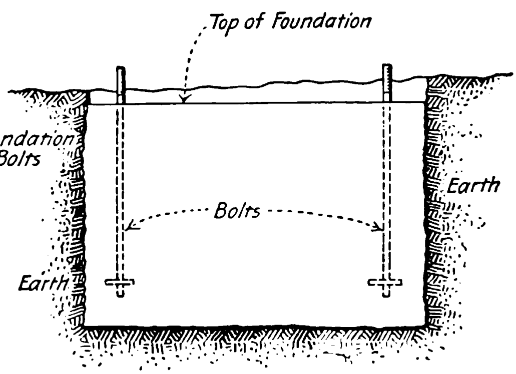


FIG. 117.—Foundation cast without forms.

tions of this type can be used for machines that have solid bed-plates, that is, for bed-plates through which air for ventilating the machine is not expected to rise. Where such a foundation, if cast solid, would be unnecessarily heavy, it can be hollowed out as suggested in Fig. 118.

Where considerable area of base is required, a solid foundation can be made, as suggested in Fig. 119, with an extended footing. The footing may consist of one or more steps. No step should be less than 8 in. thick. The "rise" and "width" of each step should be about equal. It is necessary sometimes to thus extend the base to maintain the pressure on the soil within a safe value.

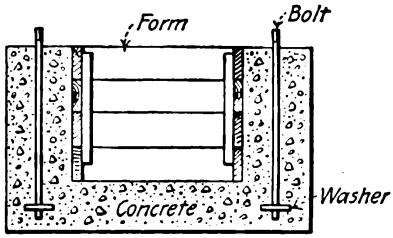


FIG. 118.—Hollowed out foundation.

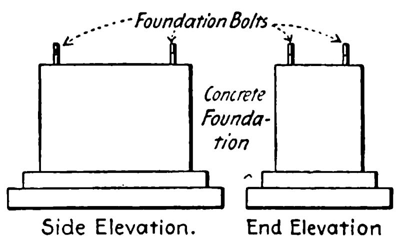


FIG. 119.—Foundation with extended footing.

Where machines have open bed-plates similar to that of Fig. 120 provision should be made for "ventilation" of the machine. It should be arranged so that air can rise all about it and keep it cool. Fig. 121 shows one type of "ventilated" foundation which is designed for the bed-plate of Fig. 120. A foundation for a large engine-driven generator can be made as suggested in Fig. 122. This design affords ample ventilation. A machine with an open

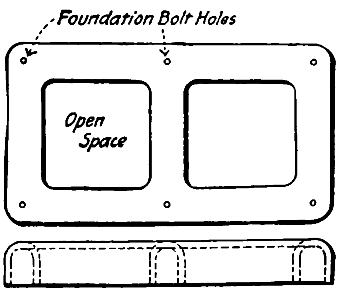


FIG. 120.—Open bed-plate.

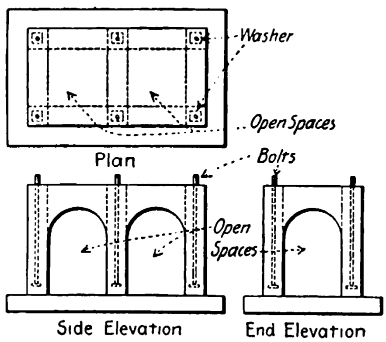


FIG. 121.—Ventilated foundation.

bed-plate can be supported on foundation columns as indicated in Fig. 123, a design used for water-wheel generators, but probably a design similar to that of Fig. 121 is better, in that it provides a support under the entire bed-plate. Undrained pits under machines should be avoided because they collect dirt and oil. A machine not exceeding 50 kw-amp. in capacity may be supported by a framework of timber. Other types of machines require heavier foundations and should be secured by foundation bolts set with a templet as above indicated. A drawing or blue-print of the generator base or bed-plate, will be furnished by the manufacturer of the machine on application.

265. Underwriters' Rules Specifying Sizes of Wires for Motor Leads.—A conductor carrying the current of only one motor must

be designed to carry a current at least 25 per cent. greater than that for which the motor is rated. Where the wires under this rule would be over-fused in order to provide for the starting current, as in the case of many of the alternating-current motors, the wires must be of such size as to be properly protected by these larger fuses. (*See modification of this rule for a special case in* **267.**)

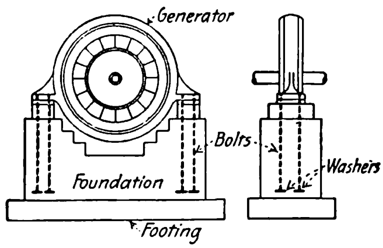


FIG. 122.—Foundation for an engine-driven generator.

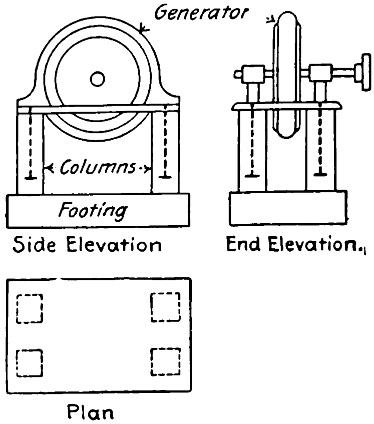


FIG. 123.—Machine supported on columns.

The current used in determining the size of a conductor carrying the current of only one varying-speed alternating-current motor must be the percentage of the 30-minute current rating of the motor as given in the following table:

Classification of Services.	Percentage of current rating of motor
Operating valves, raising or lowering rolls............	200
Rolling tables......................................	180
Hoists, rolls, ore and coal handling machines	150
Freight and passenger elevators, shop cranes, tool heads, pumps, etc.	120

Varying-speed motors are motors in which the speed varies automatically with the load, decreasing when the load increases, and vice versa. It does not mean motors in which the speed is varied by the use of different windings or grouping of winding, or motors in which the speed is varied by external means, and in which, after adjusting to a certain speed, the speed remains practically constant.

266. Wiring Table for Direct-current Motors.—The values that are here tabulated represent experience of an employee of an Underwriting Department. Table based on average efficiencies quoted by several motor manufacturers. Table is compiled on the basis of installing conductors of 25 per cent. greater carrying capacity than required for the normal full-load running current of the motors. Commercial sizes of fuses, switches, etc., have been used even though they are of slightly greater capacity than that indicated necessary by the calculations.

Where two or more motors are supplied from one service or from the same feeder, the size of service or feeder may be determined by adding together the approximate full-load currents for the different motors as given in table, and basing the conductor size on this total current.

266. Wiring Table for Direct-current Motors (*continued*)

Horse-power	Voltage[1]	Approx. full-load current	Size of fuses	Size of switch	Size of wire, B. & S. gage
¼	110	2.4	4	5	14
	220	1.2	3	5	14
	500	0.5	1	5	14
½	110	4.8	6	10	14
	220	2.4	4	5	14
	500	1.0	2	5	14
1	110	8.4	12	15	14
	220	4.3	6	10	14
	500	1.8	3	5	14
2	110	17.0	25	25	10
	220	8.5	12	15	14
	500	3.7	5	5	14
2½	110	20.0	25	25	10
	220	10.0	15	15	12
	500	4.4	6	10	14
3	110	24.0	30	30	8
	220	12.0	15	25	12
	500	5.3	8	10	14
3½	110	28.0	35	35	8
	220	14.0	20	25	12
	500	6.0	8	10	14
5	110	40.0	50	50	6
	220	20.0	25	25	10
	500	8.8	12	15	14
7½	110	60.0	75	75	3
	220	30.0	40	50	6
	500	13.5	18	25	12
10	110	80.0	100	100	1
	220	40.0	50	50	6
	500	17.5	25	25	10
15	110	120.0	150	150	00
	220	60.0	75	75	3
	500	26.3	35	35	8
20	110	154.0	200	200	0000
	220	77.0	100	100	1
	500	34.0	45	50	6
25	110	192.5	250	250	300,000
	220	96.3	125	150	0
	500	42.4	60	75	3
30	110	232.0	300	300	350,000
	220	116.0	150	150	00
	500	50.8	70	75	3
35	110	270.0	350	400	500,000
	220	135.0	175	200	000
	500	59.2	75	75	3

[1] 110-volt data applies to voltages of from 100 to 125 volts, 220-volt data to 200 to 250 volts and 500-volt data to 500 to 600 volts.

266. Wiring Table for Direct-current Motors (*continued*)

Horse-power	Voltage[1]	Approx. full-load current	Size of fuses	Size of switch	Size of wire, B. & S. gage
40	110	310.0	400	400	500,000
	220	155.0	200	200	200,000
	500	67.8	90	100	1
50	110	377.0	500	500	700,000
	220	188.5	250	250	300,000
	500	83.0	110	150	0
60	110	452.0	600	600	900,000
	220	226.0	300	300	350,000
	500	99.5	125	150	0
70	110	528.0	660	700	1,100,000
	220	264.0	350	300	500,000
	500	116.0	150	150	00
75	110	568.0	710	800	1,200,000
	220	284.0	375	400	500,000
	500	124.0	150	150	00
80	110	604.0	755	800	1,300,000
	220	302.0	375	400	500,000
	500	133.0	175	200	000
90	110	680.0	850	1,000	1,500,000
	220	340.0	450	500	600,000
	500	149.0	200	200	200,000
100	110	746.0	950	1,000	1,800,000
	220	373.0	500	500	700,000
	500	164.0	225	250	0000
125	110	934.0	1,170	1,200	2,105,500
	220	467.0	600	600	900,000
	500	205.0	275	300	300,000
150	110	1,106.0	1,390	1,500	2,400,000
	220	553.0	700	800	1,200,000
	500	245.0	325	400	400,000

[1] See note at bottom of preceding page.

267. Determining Sizes of Wire and of Fuses for Induction Motors.—*The* 1915 *National Electrical Code* rules applying to this class of wiring are substantially as follows: Rule 23*e*—"*Where rubber-covered conductor carries the current of only one A. C. motor of a type requiring large starting current, it may be protected in accordance with Table B (other insulations than rubber) of No.* 18." Rule 68*h*—"*Fuses must be so constructed that with the surrounding atmosphere at a temperature of* 75 *deg. fahr.* (24 *deg. cent.*) *they will carry indefinitely a current* 10 *per cent. greater than that at which they are rated, and at a current* 25 *per cent. greater than the rating at which they will open the circuit without reaching a temperature which will injure the fuse tube or terminals of the fuse block. With a current* 50 *per cent. greater than the rating and at room temperature of* 75 *deg. fahr.* (24 *deg. cent.*) *the fuses starting cold must blow within the time specified as follows:*

0-30 *amp.*, 1 *min.;* 31-60 *amp.*, 2 *min.;* 61-100 *amp.*, 4 *min.;* 101-200 *amp.*, 6 *min.;* 201-400 *amp.*, 12 *min.;* 401-600 *amp.*, 15 *min.*

An induction motor designed to meet the best condition of normal operation should have as low an impedance as practicable, but a motor thus designed necessarily takes a very large current in starting, this current being inversely proportional to the impedance. This starting current, therefore, varies with the load the motor must start. The average condition found in practice is 100 per cent. load. With 100 per cent. load the starting current will be about four times normal current when a starting compensator is used and very close to five times normal current when the motor is thrown directly on the line. (See Fig. 124.) These curves show that this starting current does not last over 10 sec.

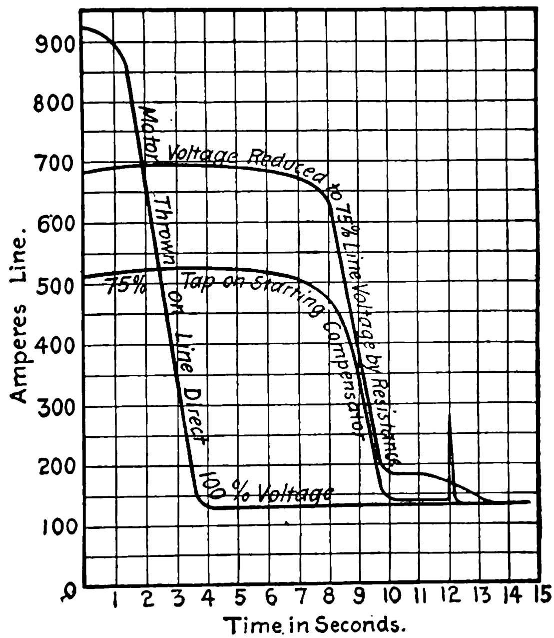


FIG. 124.—Starting currents taken by a 100-h.p., 440-volt induction motor loaded to its normal rating.

It will be found by computing the size of wire for any run of ordinary length, that the starting fuses necessitate that a larger wire be used than would be required to carry the full running current of the motor. This is still the case even when advantage is taken of Rule 23*e*, which allows rubber-covered wire to be fused to the carrying capacities given in *Table B* for wires with insulations other than rubber. However, further advantage may be taken of Rule 68*h*.

It will be found, by reference to the starting curves (Fig. 124), that the fuses will carry 50 per cent. over their normal rated capacity for a greater length of time than the duration of the starting current. From the foregoing it will therefore be evident that the size of wire for any induction motor may be computed by selecting a line fuse of

a capacity equal to two-thirds of the starting current and selecting a size of wire having the carrying capacity nearest to the rating of the fuse, using the carrying capacity given in *Table B* of the *National Electrical Code.*

There seems to be no rule regarding the fusing of weatherproof wire which makes any concession for this class of insulation, but, owing to the fact that weatherproof wire is never installed in conduit and therefore radiates effectively, it would seem to be permissible to make the same reduction from *Table B* as is made between *Tables A* and *B*.

268. The tables on alternating-current motor wiring (270 to 273) are for installations where motors do not start under full-load. The wire sizes shown are those that should be used for the branch circuit, from the main or distribution center, to the motor. Sizes of wires, switches, etc., for slow-speed motors should be larger in proportion, as the full-load currents of slow-speed motors are larger than the values given in the table, for motors of standard speed. Add 12 per cent. for speeds of 900 to 600 r.p.m. In some cases and under some circumstances this percentage will not be sufficient.

Values given in the tables for sizes of wire, switches and fuses are not large enough for motors which start under practically full-load or greater, such as motors operating pumps or compressors starting under full pressure, rock crushers, or machinery having heavy flywheels. See Sect. II, Par. 127, for data regarding starting currents of motors.

Where several motors are supplied from one service or from the same feeders, size of service or feeder wire may be determined by adding together the values in columns marked "approximate full-load current" for all of the motors. If the starting current of one motor exceeds the value of the "Weatherproof rating" of the rubber-covered wire specified in the table for use with a given horsepower, the size in the table must be increased to a size corresponding with the starting-current value.

Note that the tables are compiled on the assumption that the starting current will be about twice the running current. Code rule No. 23*e* which permits the carrying-capacity value normally allowable for wires with insulations other than rubber to be used for rubber-insulated alternating-current motor leads, determines the conductor sizes tabulated. Voltage drop is not considered in the tables.

269. The factors to be considered when designing a motor-drive for a machine are: (*Abstracted from article by A. G. Popcke, American Machinist,* Oct. 3, 1912.) The space available; the surrounding conditions; the nature of the load; the speed of the shaft where power is to be applied; the speed of the motor used; the method of connecting the motor mechanically: (*a*) Direct connected; (*b*) belted; (*c*) geared; (*d*) connected by chain drive.

270. Three-phase Induction Motor Branch Circuits, 110, 220 and 440 Volts—Fuse, Switch and Wire Sizes

(All frequencies and standard speeds. See Par. **268** for limitations)

Horse-power	110 volts					220 volts					440 volts				
	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.
1	7	14	15	15	9	4	14	10	8	5	2	14	15	4	3
2	13	10	35	30	20	7	14	15	15	9	3	14	15	6	4
3	19	8	50	40	25	9	14	25	20	12	5	14	15	10	7
5	30	6	75	60	40	15	10	35	30	20	8	14	25	20	10
7½	44	4	100	90	55	22	8	50	45	30	11	12	25	25	15
10	51	2	150	110	64	26	6	75	55	35	13	10	35	30	20
15	76	0	200	175	95	38	5	100	75	50	19	8	50	40	25
20	102	00	250	225	150	51	2	150	110	65	26	6	75	55	35
25	129	000	300	275	175	64	0	200	175	80	32	6	75	65	40
30	154	0000	400	325	200	77	0	200	175	100	39	5	100	80	50
35	175	250,000	400	350	225	88	0	200	200	110	44	4	100	90	55
40	210	350,000	500	450	275	107	00	250	225	150	54	2	150	110	70
50	246	500,000	600	600	325	123	000	250	250	175	62	2	150	125	78
75	356	700,000	800	750	450	186	300,000	400	375	250	93	0	200	200	120
100	472	1,000,000	1,000	950	600	243	400,000	500	500	325	122	000	250	250	175
150	710	1,700,000	1,500	1,450	900	362	700,000	800	750	450	181	300,000	375	375	225
200	940	....	2,000	2,000	1,200	480	1,000,000	1,000	1,000	600	240	400,000	500	500	300

[1] Starting fuses so selected as to pass 200 per cent. full-load current. [2] Running fuses so selected as to pass 125 per cent. full-load current. [3] Switches and wire so selected as to safely carry current passed by starting fuses. See Par. **268**.

271. Protection, Switches and Wire for Induction Motors—Three-phase, Three-wire, 2,200 Volts, 60 Cycles

(Underwriter's Equitable Rating Bureau, Portland, Oregon. *Electrical Review*, June 15, 1912)

Horse-power	Speed	Approximate full-load current	Size of wire, B. & S. gage	Size of oil switch in amp.	Size of starting protection, amp.	Size of running protection, amp.
15	1,800	3.7	14	60	10	5
	1,200	3.9	14	60	10	5
20	1,200	5.4	14	60	15	10
	900	5.8	14	60	15	10
25	1,200	6.5	14	60	20	10
	720	7.2	14	60	20	10
35	1,200	8.9	12	60	25	15
	720	9.8	12	60	30	15
50	900	13.7	10	60	40	20
	514	14.3	10	60	40	20
75	900	19.0	8	60	60	25
	514	20.7	8	60	60	30
100	720	24.4	6	100	75	35
	450	27.2	6	100	80	40
150	720	36.8	4	100	110	50
	450	40.9	2	200	125	60
200	600	50.0	2	200	150	75
	400	54.5	2	200	150	75

272. Single-phase Induction Motor Branch Circuits, 110 and 220 Volts—Fuse, Switch and Wire Sizes

(All frequencies, standard speeds. See Par. 268 for limitations)

Horse-power	110 volts					220 volts				
	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuses, amp.	[3] Size of running fuses, amp.
1	16	8	35	35	20	8	14	25	20	10
2	24	8	50	50	30	12	12	25	25	15
3	34	6	75	70	45	17	8	35	35	25
4	44	4	100	90	55	22	8	50	45	30
5	54	2	150	110	70	27	6	75	60	35
7½	80	0	200	175	100	40	5	100	80	50
10	106	00	250	225	125	53	2	150	110	70

[1] Switches and wire so selected as to safely carry current passed by starting fuses. [2] Starting fuses so selected as to pass 200 per cent. full-load current. [3] Running fuses so selected as to pass 125 per cent. full-load current. See Par. 268.

273. Two-phase, Four-wire Induction Motor Branch Circuits, 110 and 220 Volts—Fuse, Switch and Wire Sizes

(Standard speeds and frequencies. See Par. 268 for limitations)

Horse-power	110 volts					220 volts				
	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuse, amp.	[3] Size of running fuse, amp.	Approximate full-load current, amp.	[1] Size wire, American or B. & S. gage	[1] Size of switch, amp.	[2] Size of starting fuse, amp.	[3] Size of running fuse, amp.
1	6	14	15	12	8	4	14	10	8	5
2	11	12	25	25	15	6	14	15	12	8
3	16	8	35	35	20	8	14	25	20	10
4	18	8	50	40	25	9	14	25	20	12
5	26	6	75	55	35	13	10	35	30	20
7½	38	5	100	80	50	19	8	50	40	25
10	44	4	100	90	55	22	8	50	50	30
15	66	1	150	150	85	33	6	75	70	45
20	88	0	200	200	110	44	4	100	90	55
25	111	00	250	225	150	55	2	150	110	70
30	134	000	300	275	175	67	1	150	150	84
35	147	200,000	300	300	200	79	0	200	175	100
40	178	300,000	400	375	225	89	0	200	200	120
50	204	350,000	500	450	275	102	00	250	225	150
75	308	600,000	800	650	375	154	0000	400	325	200
100	408	900,000	1,000	850	550	204	300,000	400	400	275
150	616	....	.....	.....	800	308	600,000	800	650	400

[1] Switches and wire so selected as to safely carry current passed by starting fuses. [2] Starting fuses so selected as to pass 200 per cent. full-load current. [3] Running fuses so selected as to pass 125 per cent. full-load current. See Par. 268.

274. **The space available is the first consideration that determines the location of a motor.** In many cases it is impossible to conveniently connect a motor to accommodate the requirements of a machine. In these cases, the motor must be connected to a countershaft in a way similar to that shown in Fig. 125, or the motor can be mounted on the ceiling, on a post or girder near the machine. Belt or chain drive must be used in such cases.

A convenient location is sometimes found for a motor, but the presence of water, oil and grease or small chips renders it undesirable. Inclosed motors can be used to overcome the difficulty. The use of a semi-inclosed motor will often insure protection. If an open motor is used in such cases, it is usually placed on the ceiling, a pedestal or a near-by column or girder, a belt or chain connection being used. (A. G. Popcke, *American Machinist*, Oct. 3, 1912.)

Mechanical difficulties in finding a location for a motor can often be overcome, oil and water avoided, and compact units obtained by the addition of a countershaft at the base of a machine to which the motor is geared. Figs. 126 and 127 show the back view and side views of such an installation. Note the convenient location of the starting switch.

The nature of the work of metal-working machinery is usually

such that gears can be used wherever the motor can be placed on a machine. Machines such as punches, shears and headers, where heavy loads of short duration occur, are equipped with flywheels, which help to take up the shock; for this reason motors can be geared to this type of machine. When applying a motor to a header or any machine where a large flywheel is used, and the machine is not adapted to gearing, an easy way to apply a motor is to belt it to the flywheel.

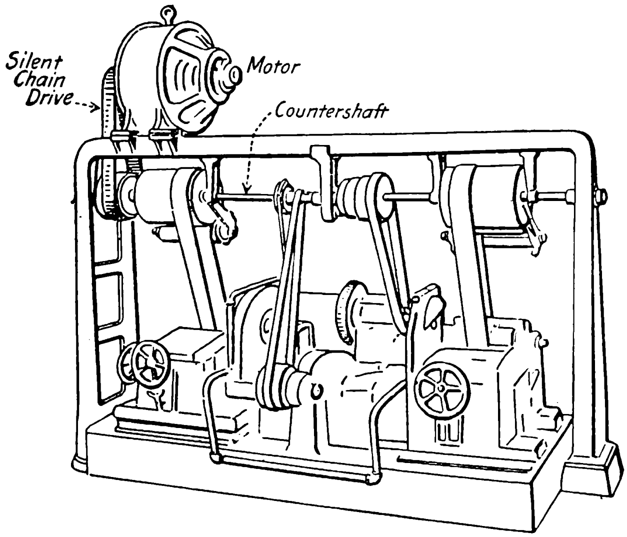


FIG. 125.—Motor driving countershaft with a silent chain.

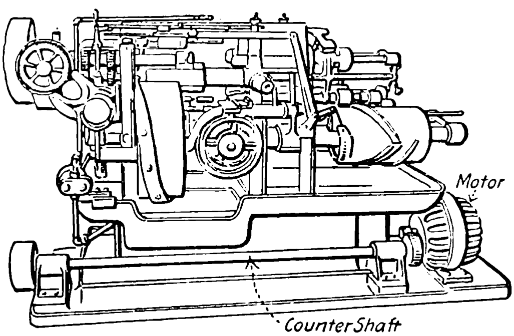


FIG. 126.—Back view showing countershaft at base.

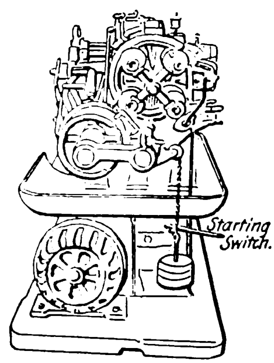


FIG. 127.—Countershaft geared to motor.

275. The speeds of the shaft on the machine to which power is applied is the principal factor which determines the speed of the motor to be connected. These speeds vary with the type of machine. On forging machines using large flywheels they are as low as 50 to 60 r.p.m.; on machine tools, such as lathes, drills, millers, etc., they average between 200 and 300 r.p.m. Speeds as high as 1,000

to 2,000 r.p.m. occur on grinders and wood-working machines. The method of taking care of these will be explained later.

276. Modern practice is to standardize the speeds of motors. This practice has been promoted by the extensive use of alternating current. Since 60 cycles is used in the majority of alternating-current systems, the standard speeds of direct-current motors are approximately the same as the speeds of 60-cycle, alternating-current motors.

The speeds obtainable with the 60-cycle motors mostly used are 1,700 to 1,800; 1,100 to 1,200; 850 to 900; 650 to 720, and 550 to 600 r.p.m. The higher speed given in each case is the synchronous speed at which the motor runs when not loaded. The speed decreases from 5 to 7 per cent. as the motor is loaded.

On 25-cycle circuits the speeds of motors most frequently used are 700 to 750; 550 to 600, and 350 to 375 r.p.m. The speeds of direct-current motors are given in the second column of Table **280**. A reference thereto will show the relation to the speeds of the alternating-current motors just given.

277. Mechanical Connections.—Motors can be either direct connected, belted, geared or connected to machines by chain drive. Direct connection with a flexible or rigid coupling can be used only where the speed of the shaft to which power is applied is the same as the motor speed. Belts, gears or chains must be used in all other cases.

278. Belt Drive of Motored Machines.—This is the most convenient method in the majority of cases and is the least expensive. It is, therefore, used more than the other two methods. The factors to be considered when applying a belt drive are: Speed reduction; pulley sizes; belt speeds; motor speed; distance between pulley centers; arc of contact; size of belt; use of idle pulleys; mounting of the motor.

279. Considerations in Obtaining Speed Reduction With a Belt Drive.—The speed reduction is the ratio of the speed of the motor to the speed of the shaft where power is applied. Obtaining the required speed reduction involves the size of the motor pulley, machine pulley and belt speed. The sizes of the pulleys used on motors have been standardized according to ratings, *i.e.*, horsepower and speed of motor. These are given in Table **280**, column 3. This fixes standard practice for belt speeds (see Table **280**, column 7).

As the diameter of a motor pulley is reduced, the strains on the motor bearings and shaft are increased. A minimum pulley is, therefore, specified by motor manufacturers for each motor rating (see Table **280**, column 5). The maximum diameter of the pulley on a motor is required only where speeds higher than the motor speed are required (grinders and wood-working machines). The maximum diameter is, in nearly all cases, limited by the belt speed, which should not exceed 5,000 ft. per minute. In some cases, with small motors especially, the size and location of the motor are such that the diameter of the motor limits the diameter of the largest pulley.

280. Standard Motor Ratings Showing the Standard and Minimum Pulleys Used in Each Case, Also Belt Speed with Standard Pulley

1	2	3	4	5	6	7	8
H.p.	R.p.m. D. C. motors	Standard pulley		Minimum pulley		Belt speed standard pulley, ft. per min.	Leather belt
		Dia.	Face	Dia.	Face		
1	1,700	3½	2½	3	1¾	1,560	Single
2	1,700	3½	3	3	3	1,560	Single
	1,200	4	3	3	3	1,250	Single
	850	4	4	3½	4	890	Single
3	1,800	4	3	3	3	1,890	Single
	1,150	4	3	3½	4	1,200	Single
	850	5	4½	4	4½	1,110	Single
5	1,800	4	4	3½	4	1,890	Single
	1,200	5	4½	4	4½	1,570	Single
	850	6	5	4½	5	1,340	Single
7½	1,700	5	4½	4	4½	2,220	Single
	1,150	6	5	4½	5	1,800	Single
	975	7	6	5	6	1,790	Single
	850	7	6	5	6	1,560	Single
	650	8	7	6	7	1,360	Single
10	1,700	6	5	4½	5	2,670	Single
	1,300	7	6	5	6	2,380	Single
	1,150	7	6	5	6	2,100	Single
	850	8	7	6	7	1,780	Single
	730	8	7	6	7½	1,530	Single
	600	9	8	6½	9	1,410	Single
15	1,700	7	6	5	6	3,100	Single
	1,250	8	7	6	7	2,620	Single
	1,100	8	7	6	7½	2,300	Single
	825	9	8	6½	9	1,940	Single
	675	10	9	7	8	1,770	Single
	600	11	10	7½	9½	1,730	Single
20	1,700	8	7	6	7	3,560	Single
	1,100	9	8	6½	9	2,600	Single
	900	10	9	7	8	2,360	Single
	750	11	10	7½	9½	2,160	Single
	650	11	10	8	9½	1,870	Single
25	1,400	9	8	6½	9	3,330	Single
	1,100	10	9	7	8	2,800	Single
	950	11	10	7½	9½	2,730	Single
	825	11	10	8	9½	2,370	Single
	600	12	12	9	10½	1,880	Double
30	1,700	9	8	6½	9	4,000	Single
	1,150	11	10	7½	9½	3,330	Single
	975	11	10	8	9½	2,800	Single
	725	12	12	9	10½	2,280	Double
	600	13	12	10	11	2,040	Double
35	1,700	10	9	7	8	4,450	Single
	1,150	11	10	8	9½	3,330	Single
	850	12	12	9	10½	2,670	Double
	675	13	12	10	11	2,300	Double
40	1,700	11	10	7½	9½	4,900	Double
	950	12	12	9	10½	3,000	Single
	775	13	12	10	11	2,640	Double
	600	14	12	12	13	2,200	Double
50	1,700	11	10	8	9½	4,900	Double
	975	13	12	10	11	3,320	Double
	750	14	12	12	13	2,750	Double
	565	16	13	12½	15	2,360	Double

281. Belt speed is figured as follows:

$$\text{Belt speed (feet per minute)} = \frac{\left(\begin{array}{c}3.14 \times \text{diam. of motor pulley} \\ \text{(inches)} \times \text{r.p.m. of motor}\end{array}\right)}{12}$$

282. The success of a belted motor application depends largely upon the arc of contact. The distance between centers of motor pulley and machine pulley, as well as the speed reduction, determine the arc of contact on the smallest pulley, usually the motor pulley. Motors can be furnished with idler-pulley attachments, Fig. 128, and these are applied to advantage where it is necessary to overcome a small arc of contact.

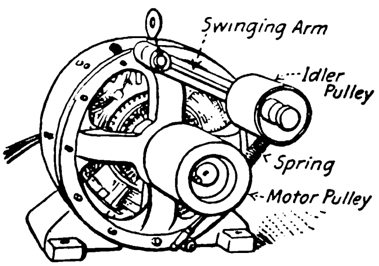


FIG. 128.—Idler pulley attachment to increase arc of contact.

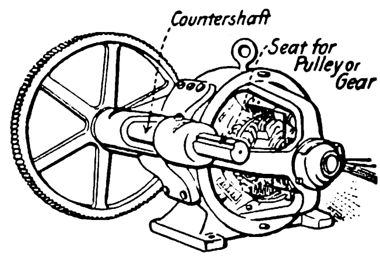


FIG. 129.—Back-geared motor suitable for extremely low speeds.

283. When necessary to obtain extremely low speeds back-geared motors should be used. (Fig. 129.) A good standard for a back-geared motor gives a speed reduction of 6 to 1 between armature and countershaft speed. Usually, if the required reduction in speed exceeds 6 to 1, a back-geared motor should be used.

Example.—If the reduction is 12 to 1 between the motor speed and the machine speed, a back-geared motor with a 6 to 1 speed reduction should be used, and the further reduction 2 to 1 obtained by means of a pulley on the countershaft of the back-geared motor.

It is poor practice in the majority of cases to use back-geared motors having an initial speed of 1,700-1,800 r.p.m. In applications requiring from 10 to 20 h.p., 1,200-r.p.m. back-geared motors should be used; above this 900-r.p.m. or 720-r.p.m. back-geared motors should be used.

284. The pulleys furnished with motors make provision for the proper width of the belt. Table 280 shows whether a single or double belt should be used. The width of the belt should be one inch narrower than the pulley face on pulleys up to 12-in. face; above that it should be two inches narrower than the pulley face.

285. The cost of a motor of given horse-power increases as the rated speed decreases. For instance, the cost of a 10-h.p. motor at 1,200 r.p.m. is approximately the same as a 5-h.p. motor at 600 r.p.m. The cost increases in the same proportion as the square root of the torque figured at 1-ft. radius. This quantity is figured by means of the following formula:

$$\text{Torque at 1-ft. radius} = \frac{5{,}250 \times \text{h.p.}}{\text{r.p.m.}}$$

Example.—A $7\frac{1}{2}$-h.p. motor at 1,150 r.p.m., ready for belting, costs approximately \$180, and a $7\frac{1}{2}$-h.p. motor at 650 r.p.m. costs approximately \$235. The torques are

$$\frac{5,250 \times 7\frac{1}{2}}{1,150} = 34.2 \text{ and } \frac{5,250 \times 7\frac{1}{2}}{650} = 60.5$$

The square roots of these are 5.85 and 7.8, respectively.
The ratio of these square roots is

$$\frac{7.8}{5.85} = 1.33$$

The ratio of prices is

$$\frac{235}{180} = 1.31$$

These two ratios check closely.

From a cost point of view, therefore, as high a speed motor as possible should be used, but a pulley diameter smaller than the minimum specified should not be used.

286. Belting Motors.—There are two general cases to be considered when belting motors; these are: (1) Where the dimensions of the machine pulley is fixed, as when belting to a flywheel. In this case the motor pulley must satisfy the requirements of the machine. Care must be taken not to use a pulley of a diameter smaller than the minimum specified. The arc of contact of the motor pulley must also be carefully considered, for the speed reduction is usually large.

(2) Where the machine pulley can be chosen to suit the standard motor pulley. Tables 289 and 288 were devised to aid in selecting the proper speed of motor and size of pulleys. Table 289 gives the machine speed at the left column and the motor speeds at the top of the table. The figures in the body of the table are the speed reductions for any combination of machine and motor speed indicated.

287. Determining the Arc of Belt Contact.—Before deciding upon any belt drive the arc of contact of the belt with the smaller pulley should be carefully checked. In machine-tool work, on applications where belts are used, the distance between centers is usually between 3 and 5 ft. Motor pulleys range in diameter from 3 to 12 in. and the arc of contact is usually considered when the ratio of reduction is between 3 and 6.

Table 288 gives the arc of contact when the size of the motor pulley, ratio of reduction and the distance between pulley centers are known.

Example.—Refer to Table 288. The motor pulley is 6 in., the ratio of reduction is 4 and the distance between centers is 5 ft.
Solution.—The table shows the arc of contact as 162 deg.

Table 291 shows the effect of the arc of contact on the transmitting power of the belt. The decrease with decreased arc of contact is expressed by a percentage which the power transmitted at a given arc of contact is of the power transmitted at 180 deg. Thus if the arc of contact is 140 deg., only 78 per cent. of the power figured by the belt formula given in a following paragraph, based on a 180-deg. arc of contact, can be transmitted.

To transmit the required power the pulley and belt width must be increased or an idler pulley must be used to increase the arc of contact.

Example.—Illustrating the application of Tables 280, 289 and 288. The speed of the machine is 185 r.p.m.; the horse-power required is 7½; the distance between centers is 5 ft. What motor speed and what pulleys should be used for the belt drive?

Solution.—Refer to Table 289. This shows that for 150 to 200 r.p.m. a 720-r.p.m. motor should be used.

Refer to Table 288. A 7½-h.p., 650-r.p.m. motor has an 8×7-in. standard pulley and a 6×7-in. minimum pulley.

The speed reduction with this motor is

$$\frac{650}{185} = 3.5$$

Refer to Table 288. The arc of contact for a ratio of reduction of 3.5 (average of 3 to 4), distance between centers of 5 ft. and 8-in. motor pulley, is 160 deg. (average of 164 and 157), and with a 6-in. motor pulley is 165 deg. (average of 162 and 168). Either will give successful service. The machine pulley would be, with an 8-in. motor pulley, 3.5×8 = 28 in. and with a 6-in. motor pulley, 3.5×6 = 21 in.

The face in either case will be 7 in. and a single 6-in. leather belt should be used. The combination of 8-in. motor pulley and 28-in. machine pulley is preferred because the motor pulley is standard.

The above example covers a case where the machine pulley can be selected at will. In cases where a motor is to be belted to a flywheel or to a pulley which cannot be easily changed, the procedure is as explained in the following.

Example.—The size of the machine pulley (flywheel) is 72 in.; the speed of the pulley is 100 r.p.m.; the horse-power required is 15, and the distance between centers is 6 ft. What motor speed and motor pulley should be used?

Solution.—Consider a reduction of 6 : 1 belted directly. The motor speed must be 600. The size of the motor pulley

$$\frac{\text{machine pulley}}{\text{ratio of reduction}} = \frac{72}{6} = 12 \text{ in.}$$

Table 280 shows that a 12-in. pulley can be used with a 15-h.p., 600-r.p.m. motor. It is 1 in. greater than the standard pulley diameter. Table 288 shows that for a 12-in. motor pulley, a ratio of reduction of 6, and 6 ft. distance between centers, the arc of contact is outside the limits of the table and very small (less than 120 deg.).

288. Arcs of Belt Contact for Different Ratios of Reduction, Distances Between Centers and Pulley Diameters

Ratio of reduction	Distance between centers, feet	Diameter of motor pulley, inches									
		3	4	5	6	7	8	9	10	11	12
3	3	170	166	163	160	157	153	150	147	145	141
	4	173	170	167	165	163	161	158	156	155	151
	5	175	172	170	168	167	164	162	161	160	157
4	3	165	160	155	150	145	142	156	132	126	122
	4	168	165	162	158	154	152	148	144	140	137
	5	172	168	166	162	159	157	155	151	148	146
5	3	160	153	148	142	134	128	122	....	....	....
	4	165	161	157	152	146	142	138	....	....	....
	5	168	164	162	157	153	150	146	....	....	....
6	3	153	147	139	131	122	.....	.....	....	....	....
	4	161	156	150	144	138	.....	.....	....	....	....
	5	164	161	156	152	146	.....	.....	....	....	....

289. Relation of Machine and Motor Speeds and Recommendations for Belt Drive

B = Motor belted direct. **Bbg** = Back-geared motor belted. Bbg = 1.33, etc., the number indicates reduction from countershaft speed if a back-geared motor with a 6 to 1 reduction is used. The heavy-faced type indicates the motor speed recommended for most cases.

Speed of driven machine	Approximate motor speed 1,800	1,200	900	720	600
1,500	1.2 **B**	...	...	...	...
1,000	1.8 **B**	1.5 B	...	...	...
800	2.2 **B**	1.5 B	1.12 B	...	...
600	3.0 **B**	2.0 **B**	1.5 B	1.2 B	1.2 B
500	3.6 **B**	2.4 **B**	1.8 B	1.44 B	1.2 B
400	4.5 B	3.0 **B**	2.25 B	1.8 B	1.5 B
350	5.13 B	3.4 **B**	2.52 **B**	2.06 B	1.7 B
300	6.0 B	4.0 B	3.0 **B**	2.4 B	2.0 B
250	7.2	4.8 B	3.6 **B**	2.9 **B**	2.4 B
200	9.0	6.0 B	4.5 B	3.6 **B**	3.0 **B**
150	12.0	8.0 Bbg 1.33	6.0 B	4.8 **B**	4.0 **B**
100	18.0	12.0 **Bbg** 2.0	9.0 Bbg 1.5	7.2 Bbg 1.2	6.0 **B**
90	20.0	13.4 **Bbg** 2.23	10.0 Bbg 1.67	8.0 Bbg 1.33	6.7 Bbg 1.11
80	22.5	15.0 **Bbg** 2.5	11.3 Bbg 1.88	9.0 Bbg 1.5	7.5 Bbg 1.25
70	25.3	17.1 Bbg 2.85	12.9 **Bbg** 2.15	10.2 Bbg 1.7	8.6 Bbg 1.43
60	30.0	20.0 Bbg 3.33	15.0 **Bbg** 2.5	12.0 Bbg 2.0	10.0 Bbg 1.67
50	36.0	24.0 Bbg 4.0	18.0 **Bbg** 3.0	14.4 Bbg 2.4	12.0 Bbg 2.0

290. Obtaining a Successful Belt Drive.—A successful drive can be obtained for the application of 287 by using a 12×10-in. pulley on the motor and employing an idler pulley. It is not customary for motor manufacturers to supply idler attachments on motors so large. In such cases an idler pulley attachment is more successful if mounted on a foundation, floor or bracket on the machine driven.

The use of a back-geared motor in a case like this is awkward because the pulley on the motor countershaft must be of large diameter. If a back-geared 1,200-r.p.m. motor were used, the countershaft speed being 200 r.p.m., a 36-in. pulley would be required on the motor countershaft, making an awkward looking drive, as this pulley would be larger than the motor.

291. Relation of Arc of Contact to Power Transmitted by Belting

Arc of contact in Degrees	Per cent. of power transmitted[1]
180	100
170	94
160	89
150	83
140	78
130	72
120	67

[1] Based on power transmitted with 180 deg. arc of contact.

292. General Rules Covering the Installation of Belting.—If possible, the lower side of the belt should be the driving side. The distance between pulley centers should be great enough to allow some sag in the upper side of the belt, or an idler pulley should be used to increase the arc of contact. The following general rules are from *Kent's Mechanical Engineers' Pocket-book.*

"1. Narrow belts over small pulleys, 15 ft. between pulley centers, the loose side of the belt having a sag of $1\frac{1}{2}$ to 2 in.

2. Medium-width belts on larger pulleys, 20 to 25 ft. between pulley centers, with a sag of $2\frac{1}{2}$ to 4 in.

3. Main belts on very large pulleys, 25 to 30 ft. between centers, with a sag of 4 to 5 in."

If the distance is too long the belt will flap unsteadily, resulting in unnecessary wear of both the belt and the bearings; if too short, the severe tension required to prevent slipping will cause rapid wear of bearings and may cause them to overheat.

The foregoing distances represent good safe practice for long life of belt and bearings. Shorter distances are frequently used but necessitate tighter belts, or the use of wider pulleys and belts, or larger pulleys and higher belt speeds. Very short belts can be made to work satisfactorily by the aid of idler pulleys, which increase the arc of contact.

It is not desirable that the slope of the belt direction be over 45 deg. from horizontal; the belt should never run vertical, if possible to avoid it, since the advantage of sag to increase the arc of contact is then lost. The pulley should be a little wider than the belt.

Belts should be run with the least tension required to prevent slipping or flapping. The slack side should have a gently undulating motion. Lateral movement of the belt on the pulley indicates poor pulley alignment or unequal stretching of the edges of the belt. Belt joints should be as smooth as possible, and a lapped joint should always trail, never lead over the pulley. Belts should be kept clean and dry; if any belt dressing is applied let it be very sparingly.

293. Minimum Distance between Pulley Centers.—A rule that has given satisfaction in practice is this. The distance between the pulley centers should not be less than 3 times the sum of the diameters of the pulleys. A better drive will result if the distance is 4 or 5 times the sum of the diameters.

294. Horse-power of Belting.—The ability of a belt to transmit power depends upon (1) the safe working effective tension allowable for the belting, (2) the arc of contact of the belt with the smaller pulley, and (3) the speed of the belt. The rule and formulas given herein are based on the assumption that the arc of contact on the smaller pulley is 180 deg. or one-half the circumference. If it is less than this, one of the correction factors given in **291** should be applied.

The effective tension is not the tension in either the loose or the tight side of the belt, but is the difference between the tensions in these two sides. It is due to the effective tension that power is transmitted by the belt. "Effective tension" is sometimes called "working tension."

It is evident that the horse-power rating of a belt is a rather flexible thing and depends entirely on how great an effective tension is considered allowable. With a heavy tension a small belt will transmit a great amount of power for a short period but will soon stretch, cease to transmit its load, and become worthless. The values given for effective tension in the accompanying tables have been proven by experiment to be ones that will provide belts of reasonably long life without excessive first cost.

295. Safe Working Effective Tension Per Inch Width for Endless Leather Belts (*Page Belting Company*).—These values apply only to belts that can be cemented at the joints by skilled workmen and thereby be made endless. For rough and ready work, for belts having their ends held together with ordinary laces or fasteners, use the belting tables given elsewhere.

Kind of belt	Approx. thickness	Working tension
Single	$\frac{3}{16}$ in.	66 lb.
Single	$\frac{1}{4}$ in.	86 lb.
Light double	$\frac{17}{64}$ in.	90 lb.
Heavy double	$\frac{18}{64}$ in.	96 lb.
Heavy double	$\frac{20}{64}$ in.	100 lb.
Heavy double	$\frac{24}{64}$ in.	120 lb.
Heavy double	$\frac{28}{64}$ in.	130 lb.

296. To Find the Horse-power a Belt of Known Dimensions will Transmit.—Multiply the safe effective working tension of the belt per inch width (take this from Table **295**) by the width of the belt in inches, and multiply this product by the speed of the belt

in feet per minute, and divide the result by 33,000. The quotient will be the number of horse-power the belt is capable of transmitting. (See the table of approximate values, **299**.)

Or, expressing this rule as a formula and combining all of the constants into one factor:

$$\text{h.p.} = \frac{W \times D \times T \times \text{r.p.m.}}{126{,}500}$$

Wherein: h.p. = horse-power belt will transmit, W = width of belt in inches, T = safe effective working tension in pounds per inch width of belt, from **295**, D is the diameter of either pulley in inches, r.p.m. = the revolutions per minute of the same pulley.

Example.—What horse-power will the light double leather belt in Fig. 130 transmit? Width = 6 in., and belt is driving a pulley 15 in. in diameter at 100 r.p.m.

Solution Using the Rule.—Safe effective working tension of light double belt is, from **295**, 90 lb. per inch width.

Speed of belt in feet per minute $= \dfrac{100 \text{ r.p.m.} \times 15 \text{ in. diam.} \times 3.1416}{12 \text{ in.}} =$ 392.7 ft. per min.

Then: $\dfrac{90 \text{ lb.} \times 6 \text{ in.} \times 392.7 \text{ ft. per min.}}{33{,}000} = 6 \text{ h.p.}$

Or solving with the formula:

$$\text{h.p.} = \frac{W \times D \times T \times \text{r.p.m.}}{126{,}500} = \frac{6 \times 15 \times 90 \times 100}{126{,}500} = \frac{810{,}000}{126{,}500} = 6 \text{ h.p.}$$

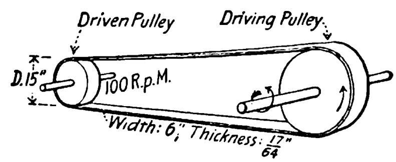


FIG. 130.—Example in finding horse-power of belting.

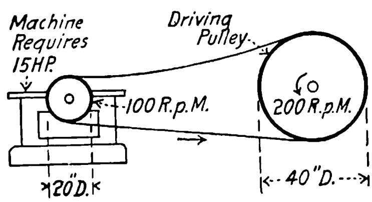


FIG. 131.—Example in finding size belt required.

297. To Find the Width of a Belt Required to Transmit a Given Horse-power.—Read the preceding paragraph. Multiply the safe effective working tension (Table **295**) per inch width by the speed of the belt in feet per minute, and divide the product by 33,000. The quotient is the horse-power a belt 1 in. wide will transmit, provided it is in contact with at least 180 deg. or one-half the pulley circumference.

Having found the amount of power for a belt 1 in. wide, divide the whole number of horse-power given by the horse-power transmitted by a belt 1 in. wide and the quotient will be the width of the belt required.

Or expressing this as a formula using the same notation as in **296**:

$$W = \frac{126{,}500 \times \text{h.p.}}{D \times T \times \text{r.p.m.}}$$

Example.—What width single thickness leather belt should be used to drive the machine of Fig. 131. Diameter of driven pulley is 20 in. Speed is 100 r.p.m.

Solution.—Safe effective working tension of single thickness belt per inch width is, from 295, 66 lb. First find the speed in feet per minute thus:

$$\frac{20 \text{ in. diam.} \times 100 \text{ r.p.m.} \times 3.14}{12 \text{ in.}} = 523 \text{ ft. per min.}$$

Then: $$\frac{66 \text{ lb.} \times 523 \text{ ft. per min.}}{33{,}000} = 1.05 \text{ h.p. per inch width of belt.}$$

Therefore $\dfrac{15 \text{ h.p.}}{1.05 \text{ h.p.}} = 14.3$ in. wide belt required. A 15-in. belt must be used.

In practice instead of using a 15-in. single thickness belt for this application a heavier or double belt would be used whereby the belt width could be decreased accordingly.

Solving the same problem using the formula:

$$W = \frac{126{,}500 \times \text{h.p.}}{D \times T \times \text{r.p.m.}} = \frac{126{,}500 \times 15}{20 \times 66 \times 100} = \frac{1{,}897{,}500}{132{,}000} = 14.3 \text{ in.}$$

A 15-in. wide belt must be used because standard belting increases in width by 1-in. increments.

298. Horse-power Transmitted by Canvas Belt (*Page Belting Company*).—Horse-power transmitted by 4-ply canvas belt = 1 h.p. for each inch wide for each 800 ft. of belt speed per minute.

6-ply belts transmit 50 per cent. more.
8-ply belts transmit 75 per cent. more than 4-ply.
10-ply belts transmit 100 per cent. more than 4-ply.
12-ply belts transmit 125 per cent. more than 4-ply.

Comparison

4-ply = single leather or 3-ply rubber.
6-ply = light double leather or 4- and 5-ply rubber.
8-ply = double leather or 6- or 7-ply rubber.
10-ply = heavy double leather or 8-ply rubber.

299. Tables of Safe Horse-power of Belting (*Page Belting Company*).—The following tables will be found useful for quickly and safely determining the amount of power that belting will transmit. It is always wise to leave a wide margin between what a belt must do and what it can do and such a margin is provided by the values in the table.

Horse-power for single leather

Width of belt	Belt speed, ft. per minute									
	600	1,200	1,800	2,400	3,000	3,600	4,200	4,800	5,400	6,000
1 in.......	1	2	3	4	5	6	7	8	9	10
2 in.......	2	4	6	8	10	12	14	16	18	20
3 in.......	3	6	9	12	15	18	21	24	27	30
4 in.......	4	8	12	16	20	24	28	32	36	40
5 in.......	5	10	15	20	25	30	35	40	45	50
6 in.......	6	12	18	24	30	36	42	48	54	60
8 in.......	8	16	24	32	40	48	56	64	72	80
9 in.......	9	18	27	36	45	54	63	72	81	90
10 in.......	10	20	30	40	50	60	70	80	90	100
12 in.......	12	24	36	48	60	72	84	96	108	120
14 in.......	14	28	42	56	70	84	98	112	126	140
16 in.......	16	32	48	64	80	96	112	128	144	160

Horse-power for double leather

Width of belt	Belt speed, ft. per minute										
	400	800	1,200	1,600	2,000	2,400	2,800	3,200	3,600	4,000	5,000
4 in.....	4	8	12	16	20	24	28	32	36	40	50
6 in.....	6	12	18	24	30	36	42	48	54	60	75
8 in.....	8	16	24	32	40	48	56	64	72	80	100
10 in.....	10	20	30	40	50	60	70	80	90	100	125
12 in.....	12	24	36	48	60	72	84	96	108	120	150
16 in.....	16	32	48	64	80	96	112	128	144	160	200
20 in.....	20	40	60	80	100	120	140	160	180	200	250
24 in.....	24	48	72	96	120	144	168	192	216	240	300
30 in.....	30	60	90	120	150	180	210	240	270	300	370
36 in.....	36	72	108	144	180	216	252	288	334	370	450
40 in.....	40	80	120	160	200	240	280	320	360	400	500

The previous rules given for figuring horse-power are more accurate than the tables, and will show that a belt can transmit more than the tables specify. The tables allow a margin of safety for the belts being laced or otherwise fastened but not "made endless," and also for a relatively small "arc of contact" on pulleys.

300. **To find the speed of a belt in feet per minute,** multiply the circumference of either pulley, in feet, by its number of revolutions per minute. To obtain the circumference, multiply the diameter by 3.14 or, roughly, by $3\frac{1}{7}$.

301. **Minimum Diameter of Pulleys for Long Life of Heavy Belts** (*Westinghouse Diary*)

For double belts.............................. 12 in.
For double belts extra flexible..................... 10 in.
For double 3-ply belts......................... 18 in.

302. **The ratio of diameter of two pulleys,** one a driver and the other driven, should not be greater than 6 to 1 for ordinary drives. That is, the diameter of the large pulley should not be more than 6 times greater than the diameter of the small one. A preferable ratio is 4 or 5 to 1.

303. **Maximum Speeds for Belts.**—Roughly, belt speeds should not exceed 1 mile (5,280 ft.) per minute. This speed is given when the diameter of either pulley in inches multiplied by its r.p.m. equals 20,000 (D$\times$r.p.m. = 20,000).

304. **Rule for Finding Length of Belts.**—When it is not feasible to measure with the tapeline the length required, the following rule, which gives a very accurate result when the pulleys are of the same diameter and an approximately accurate result when the pulleys are of different diameters, can be used:

Add the diameters of the two pulleys (D and d, Fig. 132) together, divide the result by 2 and multiply the quotient by $3\frac{1}{7}$; add the product to twice the distance (L) between the centers of the shafts and the result is the length required. All values should be expressed either in feet or in inches. Expressed as a formula, using the notation of Fig. 132, the rule becomes:

$$\text{Length of belt} = [(D+d)1.57] + 2L$$

Example.—What is the length of the belt required for the two pulleys of Fig. 133. Diameters of pulleys are 16 in. and 18 in. Distance between centers is 10 ft. or 120 in.

Solution.—Substitute in the formula:
Length of belt $= [(18 + 16)1.57] + 2 \times 120 = (34 \times 1.57) + 240 = 293.4$ in. $= \frac{293.4}{12} = 24.4$ ft.

If one pulley is considerably larger than the other a little extra allowance should be made, because the distance between the points of tangency of the belt on the two pulleys is somewhat greater than the exact distance between the centers of the shafts.

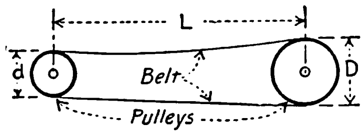


FIG. 132.—Notation for belt length formula.

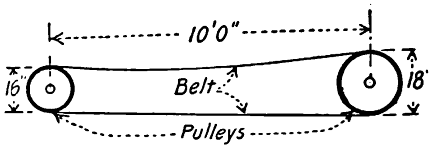


FIG. 133.—Example in finding belt length.

305. Rule for Measuring Belts in the Roll.—Add to the diameter of the roll in inches the diameter of the hole in the center of the roll. Multiply this sum by the number of coils in the roll and multiply this product by 1.32. The three figures on the left indicate the number of feet in the roll.

Example.—Roll of 5 in. single leather belt measures $37\frac{5}{8}$ in. outside diameter; hole is $4\frac{5}{8}$ in. in diameter; number of coils in roll is 84. How long is the belt?

Solution.—Using the above rule:
$37\frac{5}{8} + 4\frac{5}{8} = 42\frac{1}{4} \times 84 = 3{,}549 \times 1.32 = 4{,}684{,}68.$
Taking the first three figures on the left: The roll contains $468\frac{1}{2}$ ft. By actual measurement the roll is found to contain 469 ft.—(*Page Belting Company.*)

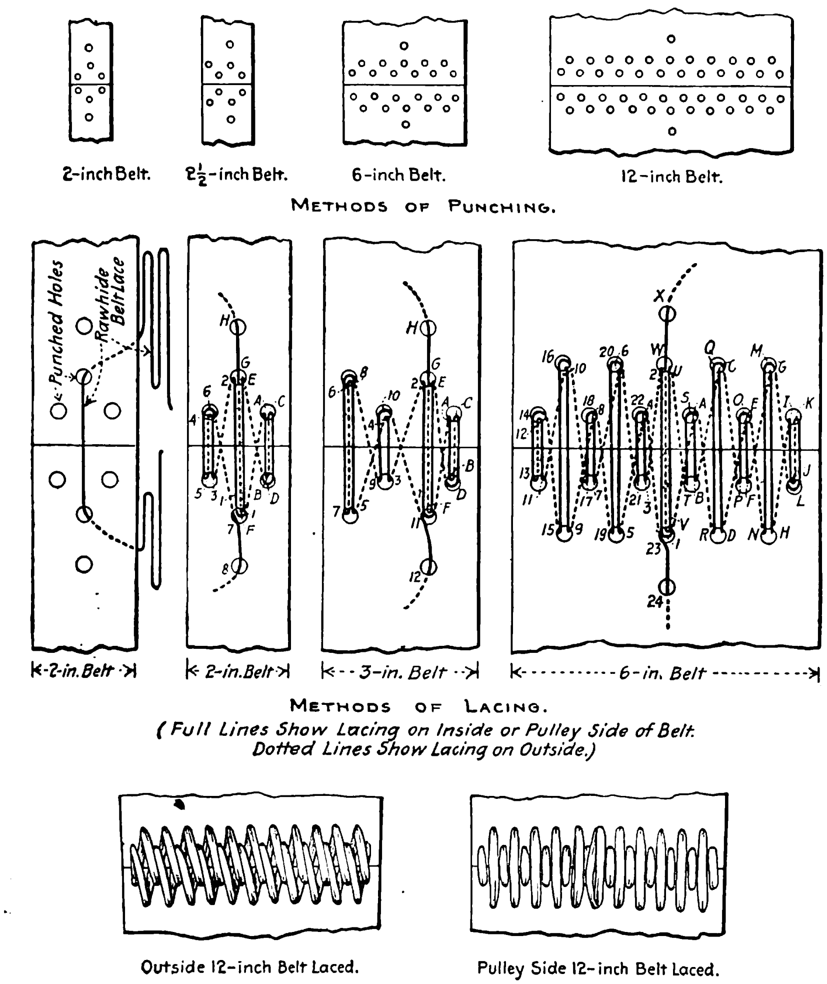
306. Ox-leather belts give the best results under ordinary conditions. No other belts will stand the shifter or shipper; cotton belts are weakened when wet; rubber belts are rotted when oiled; but leather will stand wet and dryness, cold and heat, and last a long time even when oil saturated.—(*Scientific American.*)

307. Splicing Belts (*Page Belting Company*).—Where possible the ends of the belt should be fastened together by splicing and cementing. If belts are to be laced or fastened otherwise than with cement, cut off the ends perfectly true using a try-square. Punch the holes exactly opposite one another in the two ends as in Fig. 134. The grain side of the belt should be run next to the pulley and the belt should be run off of, not against, the laps. Undoubtedly, exclusive of cementing, lacing is the best method for fastening belt ends together, as the lacing is as flexible as the belt and runs noiselessly over the pulleys. The best lacing is the cheapest. Cheap lacing is very expensive in the long run.

Use a small lace so that the holes will be small. For belts 1 in. to $2\frac{1}{4}$ in. wide, use $\frac{1}{4}$-in. lacing; $2\frac{1}{2}$ in. to $4\frac{1}{2}$ in. use $\frac{5}{16}$-in. lacing; 5 in. to 12 in. use $\frac{3}{8}$-in. lacing. For wider belts use wider lacing in proportion. Avoid thick lacing. Light, strong lacing is the best.

In punching a belt for lacing it is desirable to use an oval punch, the longer diameter of the punch lying parallel with the length of

the belt, so that a minimum amount of leather across the belt will be cut out. There should be in each end of the belt two rows of holes, placed zigzag. Make the holes the smallest possible that will admit the lace. In a 2-in. belt there should be 3 holes in each end; in a $2\frac{1}{2}$-in. belt, 4 holes; in a 3-in. belt, 5 holes; in a 4-in.



Finished Joint.

Fig. 134.—Method of lacing belts.

belt, 7 holes; in a 5-in. belt, 9 holes; in a 6-in. belt, 11 holes; in an 8-in. belt, 15 holes; in a 10-in. belt, 19 holes; in a 12-in. belt, 23 holes.

The center of no hole should come nearer to the side of the belt than $\frac{5}{8}$ of an inch nor nearer the end than $\frac{7}{8}$ of an inch. The second row should be at least $1\frac{3}{4}$ in. from the end. On wide belts these distances should be even a little greater.

Begin to lace in the center of the belt, and take much care to

keep the ends exactly in line, and to lace both sides with equal tightness. The lacing positively must not be crossed on the side of the belt that runs next to the pulley.

308. **In putting on new belts,** a common rule is to draw them up and stretch them $\frac{1}{8}$ in. for every foot in length of belt.

The strongest part of belt leather is near the flesh side, about one-third the way through from that side. It is, therefore, desirable to run the grain (hair) side on the pulley, in order that the strongest part of the belt may be subject to the least wear. The flesh side is not as liable to crack as is the grain side when the belt is old; hence it is better to crimp the grain than to stretch it. Leather belts run with the grain side to the pulley will drive 30 per cent. more than if run with the flesh side. The belt, as well as the pulley, adheres best when smooth, and the grain side adheres best because it is smoother.

309. **A belt adheres much better, and is less liable to slip, when run at a high speed than at a low speed.** Therefore, it is better to gear a mill with small pulleys, and run them at high velocity, than with large pulleys, and run slower. A mill thus geared costs less and has a much neater appearance than with large, heavy pulleys.

310. **Belt Troubles.**—The belt on any belt-connected machine should be tight enough to run without slipping, but the tension should not be too great or the bearings will heat. The crowns of driving and driven pulleys should be alike as "wobbling" of belts is sometimes caused by pulleys having unlike crowns. If this is caused by bad joints, they should be broken and cemented over again. A wave motion or flapping is usually caused by slippage between the belt and pulley, resulting from grease spots, etc. It may, however, be a warning of an excessive overload.

This fault may sometimes be corrected by increasing the tension but a better remedy is to clean the belt. A back and forth movement on the pulley is caused by unequal stretching of the edges of the belt. If this does not cure itself shortly, examine the joints. If they are evenly made and remain so, the belt is bad and should be discarded.

311. **Gear Drive.**—Gearing is the most positive form of power transmission and is usually employed when the motor can be mounted directly on a machine. The points to be considered on a gear drive are the following: (1) Speed reduction; (2) pitch of the gears; (3) number of teeth on the gears (pinion and gear); (4) face of the gear; (5) pitch line speed; (6) distance between centers; (7) use of idler gears; and (8) mounting of the motor.

The speed reduction is the same as for the belt drive. Each motor rating has a minimum pinion to limit stresses to safe values. The pitch, number of teeth and face for motor pinions have been standardized for back-gear motors and the best practice when gearing a motor directly to machines is to use these motor pinions if possible. Table 326 gives the standard motor ratings and other valuable gearing information. (The information on gear drives given herein is largely from an article in the *American Machinist*, Oct. 3, 1912, by A. G. Popcke.)

312. **The method of gearing** depends largely upon the distance between centers and the space available for the motors. In all cases the pinion must not be selected smaller than the minimum specified in **326**. The pitch-line speed must not exceed the limits given. There are two general cases covering the mounting of a motor to drive a machine through gears; these are:

(1) Where the dimension of the motor or machine limits the distance between centers of the motor shaft and the driven shaft.

(2) Where this limitation, (1), does not exist.

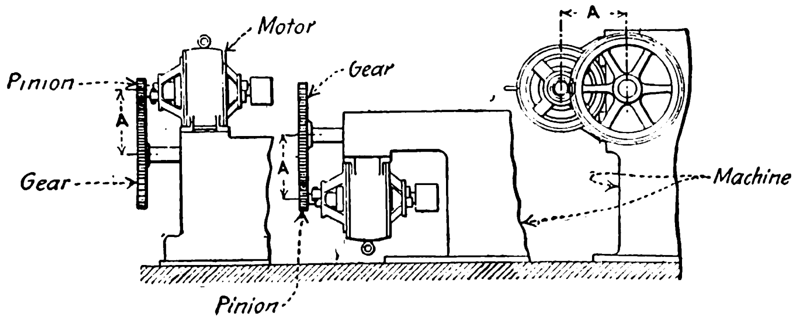


FIG. 135.—Motor mountings for gear drive (distances between gear centers limited).

The first case occurs when a motor is mounted on top, side or bottom of a machine, as shown in Fig. 135. The dimension causing limitations is indicated by *A* in these illustrations. The proper distance can be obtained by using large enough gears; the limit is pitch-line speed. An intermediate idler gear frequently overcomes the difficulties here experienced.

In the second case the relation of the motor and machine is shown in Fig. 136. In this case the motor can be mounted on a base and the motor pinion can mesh with the gear on the machine in any convenient position.

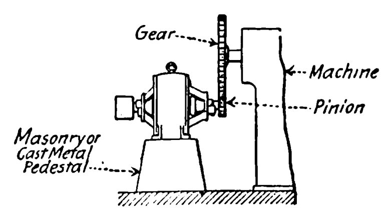


FIG. 136.—Motor mounting for gear drive (no limitation to center distance).

If reductions greater than 7 to 1 are required, it is usually necessary to obtain the reduction by the use of two sets of gears. The back-geared motors discussed under "Belt Drive" can be used to furnish one set of gears in these cases. Thus if a reduction of 10 to 1 is desired, a back-geared motor with a standard 6 to 1 reduction, with a further reduction from the countershaft of the motor to the machine of $\frac{10}{6}$ to 1 or 1.66 to 1 will fulfill the requirements.

Example.—The speed of the driven shaft of the machine is 210 r.p.m.; the h.p. is 10; the motor is mounted on the machine and the limiting distance between centers is 12 in. What are the sizes of gear and pinion to be used? The machine is a punch and shear.

Solution.—In this case a pitch-line speed of approximately 1,000 ft. per

min. will be employed. Table 326 shows that a 10-h.p. at 850 r.p.m. is the highest speed motor that can be used for this pitch-line speed. The ratio of reduction is then

$$\frac{850}{210} = 4.05 \text{ (use 4 to 1)}$$

The distance between centers for any set of gears is determined by the formula:

$$a = \frac{b}{2P}$$

where a is the distance between centers in inches, b is the sum of the number of teeth in both gears and P is the diametral pitch. In this case

$$a \text{ or } 12 = \frac{b}{2 \times 5};\ b = 120$$

The number of teeth in the pinion is,

$$\frac{b}{\text{Ratio of reduction plus 1}} = \frac{120}{5} = 24 = \text{number of teeth}$$

The number of teeth in the gear is $4 \times 24 = 96$.

Table 326 shows that the pitch-line speed for this motor with 20 teeth is 890 ft. per minute. The pitch-line speed with 24 teeth is

$$\frac{24}{20} \times 890 = 1{,}068 \text{ ft. per min.}$$

If quiet operation is desired a cloth or rawhide pinion should be used with a 3¾-in. face. Thus the gears are specified as follows:

Motor pinion—rawhide—$P = 5$, face 3¾ in., 24 teeth. Machine gear—steel $P = 5$, face 3 in., 96 teeth.

The bore for each is determined by the diameter of the shaft to which it is connected. The pinion is wider than the gears, so that the rawhide only engages with the gear. If it were the same width, the brass end-plates of the rawhide pinion would engage with the gear, causing noise.

313. **In the selection or specification of pinions for motors** (*C. W. Drake, Electric Journal*) for geared applications, three dimensions must be determined, namely, the face, diameter and pitch. These dimensions vary symmetrically according to the strength required, or, in other words, according to the torque exerted in transmitting power. As the horse-power and speed of the motor in any case determine the torque, it is evident these are the factors determining the proper dimensions of a pinion for the motor. A line of pinions with dimensions increasing symmetrically with the torque will therefore answer the purpose for all combinations of horse-power and speed. Every geared application requires special consideration, since the nature of the service, the shaft diameter, etc., may affect the dimensions of the pinion.

In gear drive the pinion is subject to most rapid wear owing to its smaller diameter. It is as important to have a pinion of good wearing qualities as it is to have one of sufficient strength and for a pinion of a given material, the ability to withstand wear depends mainly, if not wholly, on the width of the face. With a steel pinion and a cast-iron gear the former is usually the limiting factor of life and the latter the limiting factor of strength.

314. **Cast-steel gears** are about twice as strong as cast-iron, and should be used when the face of a corresponding cast-iron gear would be 4.5 in. or more, although the cost is approximately double that of cast-iron. With continuous contact all along the length of the teeth, the strength of the gear is approximately proportional to the face and the square of the circular pitch, but gear teeth seldom make such contact until worn down in service. With

new gears the whole pressure is brought to bear on the high spots, and stripping may occur before they are worn down; hence the necessity of using the stronger material.

315. Bronze and Rawhide Pinions.—For equal strength the working face of rawhide pinions must be about 25 per cent. wider than corresponding steel pinions. For quiet operation, only the rawhide should be in contact with the gear, although for high torque motors and for other severe service the gears may be widened to cover the entire pinion, thus making use of the metal flanges. Where steel pinions would make objectionable noise, rawhide pinions should be used if the stresses permit, since the pitch-line speed with a rawhide pinion is limited more by the rapid wear of the pinion than by noise. A pitch-line speed of 2,000 ft. per min. is considered a fair average limit for rawhide, but 2,500 to 3,000 ft. per min. may be used under especially favorable conditions regarding attendance, lubrication, absence of moisture or high temperature, for intermittent service, or where the life of the pinion is not important.

The wear and noise of bronze pinions are intermediate between those of rawhide and steel. Bronze pinions are particularly adapted to conditions where heat and moisture prohibit the use of rawhide. Their cost is about the same as rawhide.

316. Noise of Gears and Pitch-line Speed Limits.—Spur gears ordinarily begin to make a noticeable noise at pitch-line speeds of about 600 ft. per min., but under average conditions may not become disagreeably noisy with pitch-line speeds under 1,200 ft. per min. The amount of noise allowable depends on the noise made by surrounding machinery, on the character of the workmen, and on the nature of the work in the vicinity. A noise that would be unnoticeable in a boiler shop might be exceedingly disagreeable in a shop that was otherwise comparatively quiet. Where noise is not a limiting feature there is no limit to allowable pitch-line speeds, except the increased wear and depreciation of the motor, gears and driven machine; but depreciation may become a very important factor with high pitch-line speeds, say 2,500 ft. per minute, or sometimes even less. Tests recently made to determine a design for gears that will give the least noise and yet have sufficient strength and wearing qualities, indicate the following facts, other conditions being the same:

1. Gears having large teeth give forth a relatively greater volume of noise at a low pitch that does not carry far, while gears having smaller teeth give forth a smaller volume of noise at a higher pitch that carries farther.

2. Most of the noise comes from the gear, and not from the pinion or the motor.

3. A gear designed so that it will give a dead sound when struck a blow with a hammer will be the least noisy in operation.

317. Conditions for Noiseless Operation of Gears.—Rigid and massive supports and close fitting bearings for both the motor and the driven machine are conducive to a noiseless gear drive, and the pinion should always be placed close to the motor bearing. A gear application with motor mounted upon the ceiling might be

twice as noisy as the same application with motor mounted on a concrete foundation.

318. Pinions for High Torque Motors.—For series motors and those heavily compounded, as bending roll motors, or for motors subject to very severe service of any kind, select a pinion suitable for a constant-speed motor of the same rated r.p.m., but of about 50 per cent. higher horse-power.

319. Selection of Ratio for Back-geared Motors.—A ratio of about 6 to 1 is usually standard for back-geared motors, and should be selected wherever possible, but smaller ratios down to 3 to 1 or maximum ratios up to 7 to 1 may be obtained in certain capacities of motors for service where the conditions of the application warrant the use of such ratios. (See preceding paragraphs on this subject.)

320. Outboard Bearings for Geared Motors.—Outboard bearings should be used for geared motors of about 40 h.p. and above in heavy geared service requiring continuous operation with frequent reversing and overloads; also for all motors of about 100 h.p. and above in any geared service. The proper use of outboard bearings cannot be emphasized too strongly, since on account of increased expense there is a tendency to omit them even where good engineering demands their use.

321. How to Use the Chart for Determining Gear Dimensions (*C. W. Drake, Electric Journal*).—The dimensions for pinions for average conditions of motor-drive service are given in Fig. 137. This chart is useful in making preliminary estimates or selections of pinions for geared motors. The chart applies without correction *to steel pinions only*. The diameters are considered about standard for the various ratings, although both smaller and larger pinions can generally be used, the limiting size for small pinions being the strength and number of teeth, and, for large pinions, the pitch-line speed.

For example, to determine the steel pinion for a 5-h.p. motor at 1,200 r.p.m., find the intersection of the oblique line marked 5 *h.p.* with the horizontal line through 1,200 *r.p.m.* On the vertical line through this intersection may be found 21.9 *lb. torque*, 2.3 *in. pinion face*, 3.2 *in. pitch diameter*, and a diametral pitch of 4.85. A 2.25-in. pinion face is good practice here, since pinion-face dimensions with fractions smaller than 0.25 in. are not commonly used. The diametral pitch is also usually a whole number, except for very large pinions, where half pitches are sometimes used, so that a pitch of 5 would probably be used in the above case. Since the number of teeth is the product of the pitch diameter and the diametral pitch, the assumed pitch diameter, 3.2 in., is satisfactory with the 5 pitch, because it gives a whole number of teeth; that is, 16.

322. Gearing Definitions and Formulas.—A circle whose circumference passes through the point of contact on each tooth of a gear or pinion when this point is on the line connecting the centers of the two wheels is called the *pitch circle*. The diameter of this circle is the *pitch diameter* and its circumference is the *pitch line*.

Diameter, when applied to gears, is always understood to mean the pitch diameter.

Diametral pitch is the number of teeth to each inch of the pitch diameter. To illustrate: If a pinion has 18 teeth and the pitch diameter is 3 in., there are 6 teeth to each inch of the pitch diameter and the diametral pitch is 6.

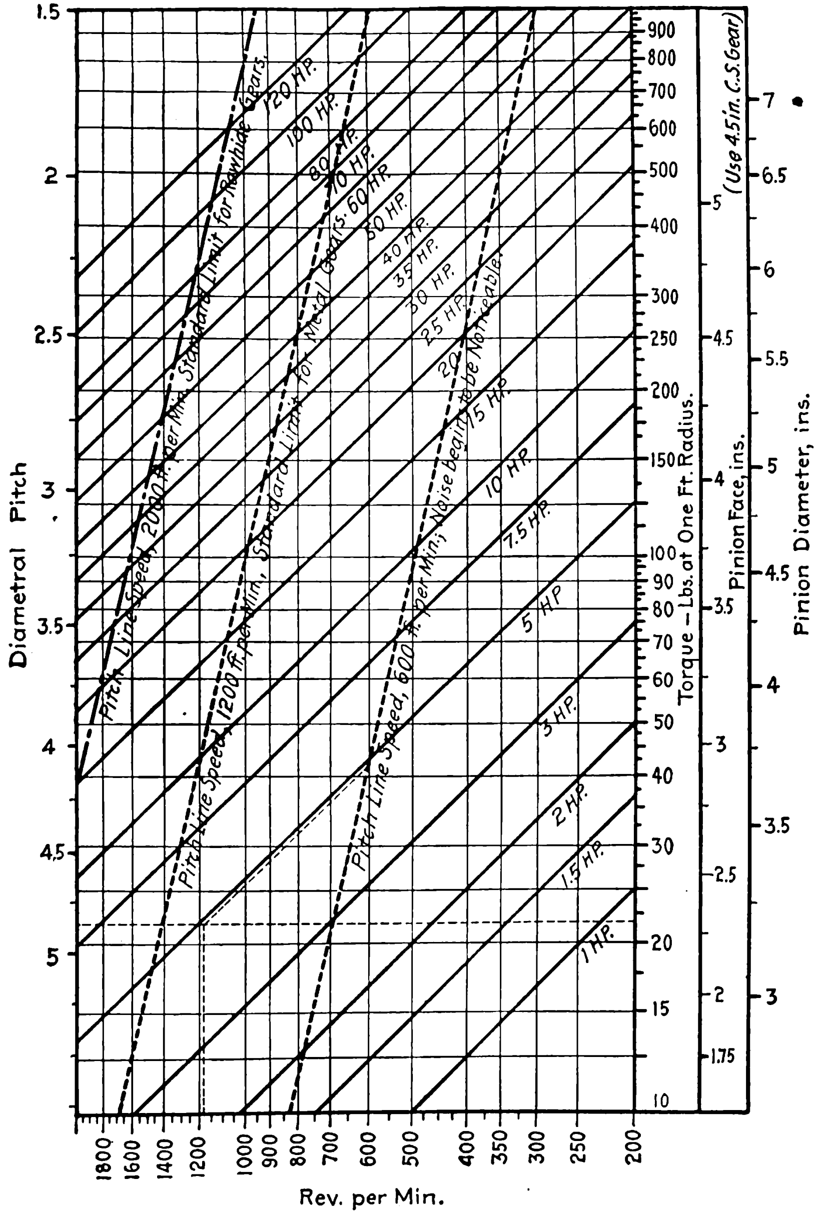


FIG. 137.—Chart for determining approximate commercial values of pinion diameter, pinion face, diametral pitch, pitch line speed, and torque, with revolutions per minute and horse-power of motor given. See accompanying paragraph for directions as to how to use.

Circular pitch is the distance from the center of one tooth to the center of the next, measured along the pitch line.

In the following formulas, for use in gear problems:

d^1 = Pitch diameter of pinion	D^1 = Pitch diameter of gear
d = Outside diameter of pinion	D = Outside diameter of gear
p = Circular pitch	n = Number of teeth on pinion
p^1 = Diametral pitch	N = Number of teeth on gear
S = Distance between centers $= \frac{1}{2}(D^1+d^1)$	r = Gear ratio $= \frac{N}{n} = \frac{D^1}{d^1} = \frac{D}{d}$

$$\pi = 3.1416$$

$$p = \frac{\pi}{p^1} = \frac{\pi d}{n+2} \quad \text{(1)} \qquad d^1 = \frac{2S}{r+1} \quad \text{(6)}$$

$$p^1 = \frac{\pi}{p} = \frac{n+2}{d} \quad \text{(2)} \qquad D^1 = \frac{2Sr}{r+1} \quad \text{(7)}$$

$$n = d^1p^1 = \frac{\pi d^1}{p} = dp^1 - 2 \quad \text{(3)} \qquad n = \frac{2Sp^1}{r+1} \quad \text{(8)}$$

$$p^1 = \frac{n}{d^1} \quad \text{(4)} \qquad N = \frac{2Sp^1 r}{r+1} \quad \text{(9)}$$

$$S = \frac{N+n}{2p^1} \quad \text{(5)} \qquad S = \frac{d^1(r+1)}{2} \quad \text{(10)}$$

323. Chain Drive.—To determine a chain drive the following information is necessary: (1) The speed of the driven shaft on the machine; (2) the speed of the motor; (3) the size of sprockets—pitch and number of teeth; (4) width of the chain; (5) the chain speed, and (6) the horse-power transmitted.

The design of chains is more complicated than that of belts and gears and it is, therefore, best to let the various chain manufacturers specify the chain, giving them the above information. The minimum sprocket to be used on a motor is the same as the minimum pinion given in Table **326**. Chain speeds should not exceed 1,200 to 1,600. ft. per min. The best practice does not exceed 1,000 ft. per min.

324. Gear and Belt Drives for Adjustable-speed Motors.—The hereinbefore mentioned tables dealt with constant-speed motors. Adjustable-speed motor problems are solved similarly. The belt speeds and pitch-line speeds must be carefully considered at the maximum speeds of the motors. The minimum pulleys and pinions are determined by the minimum speeds of the motors. Table **327** gives the ratings commonly used and pulley and gear information.

325. Vertical motors can be applied to advantage in some cases where driven shafts are vertical. Their ratings and speed characteristics are the same as those of horizontal motors.

326. Gear Data For Motor Applications.

(A. G. Popcke, *American Machinist*, Oct. 3 1912.)

Horse-power	R.p.m.	Diam. pitch	Number of teeth: Standard pinion	Number of teeth: Min. raw-hide pinion	Number of teeth: Min. pinion steel	Face: Steel	Face: Rawhide and cloth	Standard pitch-line speed	Min. diam.	Max. no. of teeth for pitch-line speed of 1,000 ft. per min.	Max. no. of teeth for pitch-line speed of 2,000 ft. per min.
1	1,700	8	17	15	13	1	1½	940	1.63	18	36
1	1,200	8	17	15	13	1½	2	665	1.63	25	50
2	1,700	8	17	15	13	1½	2	940	1.63	18	36
2	1,200	8	22	20	19	1¾	2¼	870	2.38	25	50
2	850	6	18	21	19	1¾	2¼	615	2.38	36	72
3	1,800	8	22	20	19	1¾	2¼	1,300	2.38	....	34
	1,150	8	22	21	19	1¾	2¼	830	2.38	26	52
	850	6	18	18	18	2¾	3⅜	670	3.0	27	54
5	1,800	8	22	21	19	1¾	2¼	1,300	2.38	....	34
	1,200	6	18	18	18	2¾	3⅜	940	3.0	19	38
	850	6	21	19	18	2¾	3⅜	990	3.0	27	54
7½	1,700	6	18	18	18	2¾	3⅜	1,400	3.0	....	26
	1,150	6	21	19	18	2¾	3⅜	1,050	3.0	20	40
	975	5	19	18	18	3	3¾	970	3.6	19	38
	850	5	19	18	18	3	3¾	850	3.6	22	44
	650	5	20	18	18	3	3¾	685	3.6	29	58
10	1,700	6	21	19	18	2¾	3⅜	1,420	3.0	....	27
	1,300	6	22	19	18	2¾	3⅜	1,250	3.0	....	35
	1,150	5	19	18	18	3	3¾	1,150	3.6	....	33
	850	5	20	18	18	3	3¾	890	3.6	22	44
	730	5	21	18	18	3½	4¼	805	3.6	26	52
	600	5	21	19	19	3½	4¼	665	3.8	31	62
15	1,700	5	19	18	18	3	3¾	1,700	3.6	....	22
	1,250	5	20	18	18	3	3¾	1,300	3.6	....	30
	1,150	5	21	18	18	3½	4¼	1,210	3.6	....	35
	825	5	21	19	19	3½	4¼	910	3.8	23	46
	675	4½	22	18	18	4	5	870	4.0	25	50
	600	4½	22	19	19	4	5	770	4.22	29	58
20	1,700	5	20	18	18	3	3¾	1,780	3.6	....	22
	1,100	5	21	19	19	3½	4¼	1,220	3.8	....	35
	900	4½	22	18	18	4	5	1 150	4.0	19	38
	750	4½	22	19	19	4	5	960	4.22	23	46
	650	4	21	18	18	4¼	5¼	890	4.5	23	46
25	· 1,400	5	21	19	19	3½	4¼	1,550	3.8	....	27
	1,100	4½	22	18	18	4	5	1,400	4.0	....	31
	950	4½	22	19	19	4	5	1,220	4.22	....	36
	825	4	21	18	18	4¼	5¼	1,130	4.5	18	36
	600	4	22	19	18	4¼	5¼	860	4.5	25	50
30	1,700	5	21	19	19	3½	4¼	1,880	3.8	....	22
	1,150	4½.	22	19	19	4	5	1,470	4.22	....	30
	975	4	21	18	18	4¼	5¼	1,330	4.5	....	31
	725	4	22	19	18	4¼	5¼	1,050	4.5	21	42
	600	3¼	20	....	18	4½	..	970	5.53	20	40
35	1,700	4½	22	18	18	4	5	2,180	4.0	....	20
	1,150	4	21	18	18	4¼	5¼	1,580	4.5	....	27
	850	4	22	19	18	4¼	5¼	1,220	4.5	18	36
	675	3¼	20	....	18	4½	..	1,080	5.53	18	36
40	1 700	4½	22	19	19	4	5	2,180	4.22	....	20
	950	4	22	19	18	4¼	5¼	1,370	4.5	....	32
	775	3¼	20	....	18	4½	..	1,250	5.53	....	32
	600	3	18	....	15	4½	..	940	5.0	19	38
50	1,700	4	21	18	18	4¼	5¼	2 340	4.5	....	18
	975	3¼	20	....	18	4½	..	1,580	5.53	....	25
	750	3	18	....	15	4½	..	1,170	5.0	15	30
	565	3	20	....	18	4½	..	990	6.0	20	40

327. Adjustable-speed Motor Ratings and Pulley and Gear Data For Use When Connecting Adjustable-speed Motors to Drive Machinery

(A. G. Popcke, *American Machinist*, Oct. 3, 1912.)

Horse-power	R.p.m.		Smallest pulley		Gear data					Pitch-line speed, at min. diam.		Max. teeth not to exceed 2,000 ft. per min. at max. speed
					Pitch	Face		Min. teeth	Min. diam			
	Min.	Max.	Dia.	Face		Steel	Rawhide			Min. speed	Max. speed	
1	740	2,200	3	3	8	1¾	2¼	19	2.38	460	1,380	27
	600	1,800	3	3	8	1¾	2¼	19	2.38	375	825	46
	450	1,800	3	4	8	1¾	2¼	19	2.38	280	1,120	34
2	1,100	2,200	3	3	8	1¾	2¼	19	2.38	690	1,380	27
	740	2,200	3	4	8	1¾	2¼	19	2.38	460	1,380	27
	450	1,800	4	4½	6	2¾	3⅜	18	3.0	355	1,420	25
3	1,000	2,000	3	4	8	1¾	2¼	19	2.38	625	1,250	30
	660	2,000	4	4½	6	2¾	3⅜	18	3.0	520	1,560	23
	450	1,800	4½	5	6	2¾	3⅜	18	3.0	355	1,422	25
	375	1,500	5	6	6	2¾	3⅜	18	3.0	294	1,176	30
5	1,000	2,000	4	4½	6	2¾	3⅜	18	3.0	790	1,580	23
	750	1,500	4½	5	6	2¾	3⅜	18	3.0	590	1,180	30
	600	1,800	5	6	6	2¾	3⅜	18	3.0	470	1,410	25
	450	1,800	6	7	5	3	3¾	18	3.6	425	1,700	21
	375	1,500	6	7½	5	3½	4¼	18	3.6	355	1 420	25
7½	900	1,800	5	6	6	2¾	3⅜	18	3.0	705	1,410	25
	800	1,600	5	6	5	3	3¾	18	3.6	755	1,510	24
	600	1,800	6	7	5	3	3¾	18	3.6	570	1,710	21
	500	1,500	6	7½	5	3½	4¼	18	3.6	475	1,425	25
	450	1,800	6½	9	5	3½	4¼	19	3.8	450	1,800	21
	350	1,400	6½	9	5	3½	4¼	19	3.8	350	1,400	27
10	850	1,700	6	7	5	3	3¾	18	3.6	800	1,600	22
	750	1,500	6	7	5	3	3¾	18	3.6	710	1,420	25
	600	1,8co	6	7½	5	3½	4¼	18	3.6	570	1,710	21
	500	1,500	6½	9	5	3½	4¼	19	3.8	500	1,500	25
	450	1,800	6½	9	5	3½	4¼	19	3.8	450	1,800	21
	375	1,500	7	8	4½	4	5	18	4.0	390	1 560	23
15	780	1,560	6½	9	5	3½	4¼	19	3.8	780	1 560	24
	600	1,200	7	8	4½	4	5	18	4.0	630	1,260	28
	500	1,500	7½	9½	4½	4	5	19	4.22	555	1,665	23
	400	1,200	8	9½	4	4¼	5¼	18	4.5	470	1,410	25
	375	1,500	9	10½	4	4¼	5¼	18	4.5	440	1,760	20
20	650	1,300	7½	9½	4½	4	5	19	4.22	720	1 440	26
	550	1,100	8	9½	4	4¼	5¼	18	4.5	645	1,290	28
	500	1,500	9	10½	4	4¼	5¼	18	4.5	590	1,770	20
	400	1,200	10	11	3¼	4½	....	18	5.53	580	1,740	21
	300	1,200	12	13	3	4½	....	15	5.0	390	1,560	19
25	550	1,100	9	10½	4	4¼	5¼	18	4.5	645	1,290	28
	400	1,200	12	13	3	4½	....	15	5.0	525	1,575	19
	300	1,200	12½	15	3	4½	....	18	6.0	470	1,880	19
30	550	1,100	10	11	3¼	4½	....	18	5.53	800	1,600	23
	350	1,050	12½	15	3	4½	....	18	6.0	550	1,650	22
	250	1,000	14	18	3	4½	....	18	6.0	390	1,560	23
40	550	1,100	12	13	3	4½	....	15	5.0	720	1,440	21
	350	1,050	12½	15	3	4½	....	18	6.0	550	1,650	22
	250	1,000	16	21	3	4½	....	19	6.33	415	1,660	23
50	500	1,000	12½	15	3	4½	....	18	6.0	790	1,580	23
	325	975	16	21	3	4½	....	19	6.33	540	1,620	23

328. Speeds of Pulleys and Gears.—The fact that the circumference of a pulley or gear is always 3.1416 (or roughly $3\frac{1}{7}$) times its diameter renders it easy to compute speeds by considering only the diameters of both driver and driven pulleys. Belting from one 6-in. pulley to another gives the same speed to both; but if the driving pulley has a diameter of 16 in. and the driven pulley one of only 4 in., it is evident that the small pulley will make 4 complete revolutions for each revolution of the large pulley. If the positions of the pulleys are reversed and the small pulley is made the driver, the large pulley will make but one revolution for every four of the small pulley. The same rule applies to gears if the pitch diameter and not the outside diameter is taken. Or instead of the pitch diameter the number of teeth in the gears may be considered. See Table 329 for rules for determining pulley and gear speeds and diameters. (*American Machinist's Handbook.*)

329. Rules for Determining Pulley Speeds and Diameters.—These rules apply equally well to a number of pulleys belted together or to a train of gears if all the driving and all the driven pulley diameters and speeds are grouped together.

Having	To find	Rule
Diam. of driving pulley Diam. of driven pulley Speed of driving pulley	Speed of driven pulley	Multiply diam. of driving pulley by its speed and divide by diam. of driven pulley
Diam. of driving pulley Speed of driving pulley Speed of driven pulley	Diam. of driven pulley	Multiply diam. of driving pulley by its speed and divide by speed of driven pulley
Diam. of driving pulley Diam. of driven pulley Speed of driven pulley	Speed of driving pulley	Multiply diam. of driven pulley by its speed and divide by diam. of driving pulley
Diam. of driven pulley Speed of driven pulley Speed of driving pulley	Diam. of driving pulley	Multiply diam. of driven pulley by its speed and divide by speed of driving pulley

330. An Easy Way to Remember the Rules for Pulley Speeds and Diameters.—The speed and the diameter of one of the pulleys is always known and either the speed or the diameter of the other pulley is known. Always multiply together the two quantities (the speed and diameter) which relate to the same pulley and then divide this product by the other quantity (either the speed or the diameter as the case may be) which relates to the other pulley. The quotient will be value desired.

SECTION III

OUTSIDE DISTRIBUTION

POLE LINES

1. **The reports of the committee on overhead line construction of the National Electric Light Association** contain what are probably the best and most complete specifications for pole-line construction for lighting and power distribution that have ever been compiled. Much of the matter in this section regarding pole lines has been abstracted from those reports.

2. **Northwestern Cedarmen's Specifications for Poles.**—"Sizes 5 in., 25 ft. and upward.

"Above poles must be cut from live growing timber, peeled and reasonably well proportioned for their length. Tops must be reasonably sound and when seasoned must measure as follows:

"5-in. poles, 15 in. circumference at top end.
"6-in. poles, $18\frac{1}{2}$ in. circumference at top end.
"7-in. poles, 22 in. circumference at top end.

"If poles are green, fresh cut or water soaked, then 5-in. poles must be 5 in. plump in diameter at the top end, 6-in. poles must be $19\frac{1}{2}$ in. in circumference, and 7-in. poles $22\frac{3}{4}$ in. in circumference at top end.

"One way sweep allowable not exceeding 1 in. for every 5 ft.; for example, in a 25-ft. pole, sweep not to exceed 5 in. and in a 40-ft. pole 8 in.; in longer lengths 1 in. additional sweep permissible for each additional 5 ft. in length. Measurement for sweep shall be taken as follows: That part of the pole when in the ground (6 ft.) not being taken into account when arriving at sweep, tightly stretch a tape line on the side of the pole where the sweep is the greatest, from a point 6 ft. from butt to the upper surface at top, and having so done measure widest point from tape to surface of pole, and if, for illustration, upon a 25-ft. pole said widest point does not exceed 5 in. said pole comes within the meaning of these specifications.

"Butt rot in the center including small ring rot outside of the center, total rot must not exceed 10 per cent. of the area of the butt.

"Butt rot of a character which plainly seriously impairs the strength of the pole above ground is a defect.

"Wind twist is not a defect unless very unsightly and exaggerated.

"Rough large knots, if sound and trimmed smooth, are not a defect."

NOTE.—Large purchasers ordinarily adopt somewhat more rigid specifications than the above.

3. **The Best Wood for Poles.** (*The Standard Handbook.*)—Cedar is believed on the whole to be the best wood for poles, but on the Atlantic coast the supply of this timber is nearly exhausted. Chestnut stands next, but this tree is more slender and hence is

likely to be weaker for the same diameter of top. In the South, yellow pine would appear to be the natural pole, but notwithstanding the pitchy quality of this wood it rots with alarming rapidity after being cut and set in the ground, so that juniper or cypress is chiefly used. In the middle West so-called Norway pine, usually cut in the forests of Oregon or in the Canadas, can be secured. On the Pacific Coast red wood is used to a large extent.

4. Weights of Wood Poles

Length of pole	Cedar—weight in lb.				Chestnut—weight in lb.		
	5-in. top	6-in. top	7-in. top	8-in. top	6-in. top	7-in. top	8-in. top
20	125	180	240	....	.....	....	....
25	200	260	340	430	500	600	720
30	290	360	450	580	600	800	940
35	400	480	600	760	.....	1,030	1,200
40	.....	640	780	980	.....	1,310	1,520
45	.....	830	1,020	1,270	.....	1,660	1,940
50	.....	1,050	1,300	1,600	.....	2,080	2,480
55	.....	1,310	1,640	2,000	.....	2,600	....
60	.....	....	2,080	.....	.....	....	....

The above figures are the average of shipping weights used by a large number of dealers in poles. Although poles are usually designated by the diameter of the top, as "5-in," "6-in," etc., this may be misleading, because an acceptable pole may not be exactly circular. The circumference of the top should be measured with a tape line and for seasoned poles should be approximately as follows: 5-in. poles, 15 in. circumference at top; 6-in. poles, 18½ in. circumference at top; 7-in. poles, 22 in. circumference at top.

5. Dimensions of Poles for Lighting and Power Lines.—The table gives average dimensions for poles for light transmission lines or for ordinary distribution lines. Heavier poles are used for heavy lines and lighter ones for lighter lines.

Length, feet	Cedar		Juniper		White chestnut	
	Cir. at top, inches	Cir. 6 ft. from butt, inches	Cir. at top, inches	Cir. 6 ft. from butt, inches	Cir. at top, inches	Cir. 6 ft. from butt, inches
25	25	36	25	36	....	....
30	25	40	25	38	22	36
35	25	43	25	43	22	40
40	25	47	25	47	22	43
45	25	50	25	50	22	47
50	25	54	25	54	22	50
55	25	56	25	56	22	53
60	25	63	25	59	22	56
65	25	66	25	63	22	59
70	....	....	....	....	22	62
75	....	....	....	....	22	65
80	....	....	....	....	22	69

6. Preserving Poles. Creosoting. (*Standard Handbook*).—Owing to the increasing scarcity of timber there is a growing interest in preservative methods that endeavor to impregnate the pole with some chemical solution which shall successfully resist or retard decay, but with the exception of what is called creosoting few have found much favor. By this method the pole is placed in a large tank hermetically sealed. After the tank is closed superheated steam is applied and the pole cooked sufficiently to raise its temperature to about 250 deg. fahr. Then by means of an air pump the tank is exhausted and the sap in the pole tends to flow outward and may be removed from the tank. This is intended to thoroughly season the pole, after which the tank is filled with dead oil of tar (creosote) and hydrostatic pressure applied, until such a quantity of oil is forced into the timber as may be specified.

It is usual to specify that creosoting shall be done with a steam pressure of not less than 45 lb. applied for not less than 4 hr. and then a vacuum of not less than 20 in. until all sap ceases to flow. The dead oil of tar (creosote) should be liquid at 100 deg. fahr., should contain at least 25 per cent. of constituents that do not volatilize at a temperature of 600 deg. fahr., should not contain over 5 per cent. of tar acid and no admixture of any substance not derived from the distillation of coal tar. After the oil is pumped into the tank it is usual to require that from 12 lb. to 25 lb. per cubic foot of timber shall be forced into the wood. The amount of oil is determined by noting the quantity pumped into the tank and the quantity pumped out after treatment, the difference being that absorbed by the wood. This difference divided by the volume of the timber treated gives the quantity of oil absorbed. The creosoting process is growing in favor.

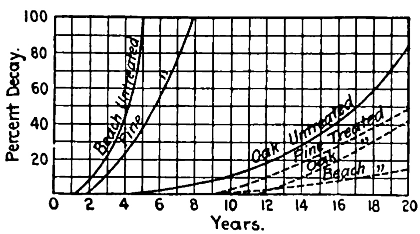


FIG. 1.—Life of treated and untreated poles.

Fig. 1 shows, as would be expected, that the softer and more porous woods that suffer most rapid decay are most benefited, and have the longest life after treatment. Such woods can absorb the most oil. The cost of treatment varies with the amount of oil injected and local conditions. Roughly, it usually about doubles the cost of the timber, while the life is increased from three to ten fold.

7. Steel poles are used because of their reliability and good appearance. Such poles are built up of structural steel, or made of special tubes. Poles made up of sections of wrought-iron pipe welded together are very common in railway work along city streets.

8. Reinforced-concrete poles (*Standard Handbook*) are the most permanent and usually the most expensive. The life of a properly designed concrete pole is practically unlimited. The facility with which special purposes may be served with reinforced concrete is also a great advantage. The exterior form may easily be modified to harmonize with any desired scheme of decoration.

When it is desired to lead wires from the pole top to ground, the poles may be made hollow, and thus at a slight additional cost the wires are completely hidden from view and protected from the weather. Concrete poles may fail, but they will not fall to the ground. The principal drawback to this form of construction has been the cost and the difficulty of manufacture. They are heavy and cumbersome to transport, so that, where possible, it is well to make them in the neighborhood where they are to be used. Both concrete and steel poles may be transported in small packages over mountains and erected on the spot, but in this respect steel is much superior to concrete.

9. Cost of Concrete Poles.—The cost of installation depends to such a great extent upon the accessibility of the point of erection that it is impossible to give any general rule for its determination. Certain reinforced-concrete poles 35 ft. high 6 × 6 in. at the top and 14 × 14 in. at the butt weighed 2,500 lb. and cost to build $15 each. Another type of reinforced-concrete pole 35 ft. long, 7 in. diameter at the top and 11 in. diameter at the butt cost $11 to build, cement being $1.50 a barrel, sand $2 per cu. yd. and labor $2 per day. A 60-ft. pole for a 500-ft. span, 14 in. diameter at the butt, designed to carry a direct pull of 16,000 lb. at the top and a torsional effect of an arm 4 ft. long carrying 8,000 lb., cost $160 each.

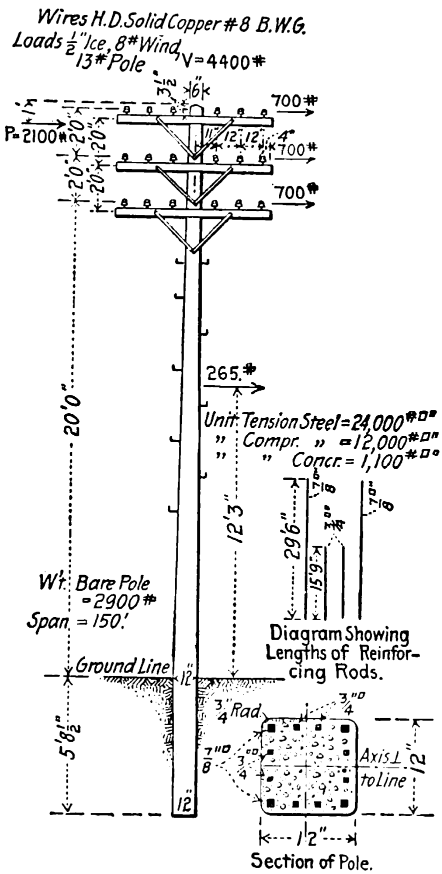


FIG. 1A.—A 30-ft. reinforced concrete pole (Universal Portland Cement Co.).

10. The design of reinforced concrete poles requires considerable skill. Where one who is unfamiliar with concrete pole design must build them, he had best accept the proportions of poles that have been built and that are giving good service. A very useful booklet—*Concrete Poles*—will be mailed free to any one interested by the Universal Portland Cement Co. of Pittsburg. This book gives the dimensions of many concrete poles. The design of Fig. 1A is from the booklet. The pole is proportioned, for a 150-ft. span, to successfully withstand a gale, with the wind at a velocity of 70 miles per hour, and ½-in. ice on the wires. The horizontal load thus imposed by the wind on all of the 18 wires, tending to

overturn the pole, is 2,100 lb. The sides of the reinforcing bars are $1\frac{1}{4}$ in. in from the faces of the pole. The concrete is a 1:2:4 mixture. It should be mixed wet, using carefully selected materials with the fine aggregate next to the forms. Air-bubbles should be eliminated by careful tamping or churning. Corners of the pole should be chamfered off. The square reinforcing rods, which are of the mechanical bond type, are bound together by a web system not shown in the illustration. The web system consists of a spiral of No. 12 steel wire wound outside of the rods and securely bound to them. The rods are also secured together with horizontal ties 1 in. wide and $\frac{1}{4}$ in. thick, spaced 3 ft. to 5 ft. apart. The reinforcement thus forms an independent skeleton which can be assembled and lowered into the forms. It is stated that it is most economical to cast poles exceeding 35 ft. in height in their final vertical positions. Shorter poles are erected with a derrick. Gains for cross-arms and holes for bolts are cast in poles. Metal pole steps may be cast in solid also.

11. Depth to Set Poles in the Ground.

One rule is that they should, on straight lines, be set in the ground $\frac{1}{6}$ of their lengths. The following table indicates good practice for normal soils.

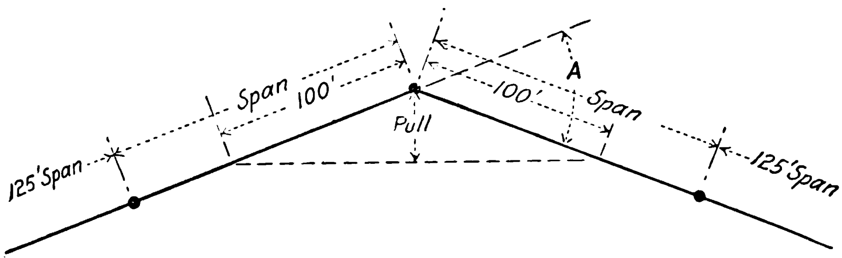
Pole length, over all, in feet	Depth to set in ground	
	Straight lines	Curves, corners, and points of extra strain
30	5.0 ft.	6.0 ft.
35	5.5 ft.	6.0 ft.
40	6.0 ft.	6.5 ft.
45	6.5 ft.	7.0 ft.
50	6.5 ft.	7.0 ft.
55	7.0 ft.	7.5 ft.
60	7.0 ft.	7.5 ft.
65	7.5 ft.	8.0 ft.
70	7.5 ft.	8.0 ft.
75	8.0 ft.	8.5 ft.
80	8.0 ft.	8.5 ft.

12. The size of pole to use cannot be definitely specified without knowing local conditions. Municipal ordinances sometimes regulate the heights of poles and wires. Where there are trees along the line, the wires should be carried entirely above them or through the lower branches, which interfere less than do the higher ones where the foliage is thicker. For lines on highways it is usually customary to place the lowest wire at least 18 ft. above the highway and 21 ft. is better. Railway companies frequently specify 22 ft. between the top of the rail and the lowest cross-arm. Wires should be at least 15 ft. above sidewalks. The height of the pole will depend upon the number of cross-arms to be carried. It is desirable to avoid abrupt changes in the level of wire, so where the line runs up hill and down dale shorter poles should be used on the hill tops and longer ones in the valleys.

Guy wires should be at least 18 ft. above a highway and 12 ft. above a sidewalk.

In cities it is good practice to use 35-ft. poles to carry either one or two cross-arms; 40-ft. poles to carry three or four cross-arms; and 45-ft. poles to carry over four cross-arms. For suburban lines 30-ft. poles are often used. For very light lines carrying only three or four wires, 6-in. poles 25 ft. long are sometimes used, though so light a pole is inexpedient if the number of wires is likely to increase. The height of a pole is always considered as the total length over all.

13. **Poles should be spaced,** in straight portions of a line, about 125 ft. apart. In curves and at corners the spans should be about as indicated in Fig. 2.



Note: If the "Pull" is less than 5', the Spans Adjacent to the Angle Pole shall be Standard Length (125'). If the "Pull" exceeds 5', the Spans Adjacent to the Angle Pole shall be Reduced to the Distance "Span" Given in Table.

Angle A.	Pull in feet.	Span	No. of 6000 lb. Side Guys.		
			1 Arm 6 Wires.	2 Arms 12 Wires.	3 Arms 18 Wires.
Less than 6°	Less than 5'	125'	None	None	None
6°–11°	5'–10'	115'	None	1	1
11°–15°	10'–13'	105'	1	1	1
15°–22°	13'–19'	95'	1	1	2
22°–30°	19'–26'	85'	1	1	2
Over 30°	Over 26'	75'	1	2	2

FIG. 2.—Pole spacing and side guys on curves (National Electric Light Association).

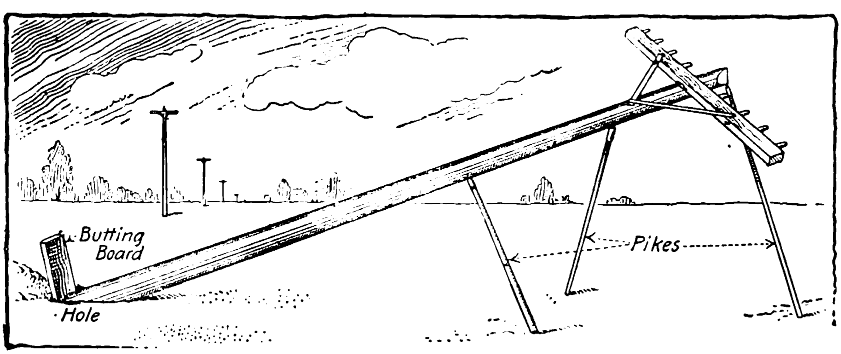


FIG. 2A.—Method of setting a pole with pikes.

14. **Holes for poles** should be large enough to admit the poles without any slicing or chopping and should be of the same diameter from top to bottom. The diameter of the hole should always be at least large enough so that a tamping bar can be worked on all sides between the pole and the sides of the hole.

15. **Setting Poles.**—On straight lines poles should be set perpendicularly. On curves poles should slant slightly so that the tension of the wires will tend to straighten them. In filling a hole after the pole is in it, only one shoveler should be employed and as many more men as can conveniently work around the pole should tamp in the earth as the shoveler throws it in. Some of the surplus earth should be piled around the butt of the pole so the water will drain away. Fig. 2A illustrates the method of setting a pole with pikes.

16. **Setting Poles in Loose and Weak Soils.**—Where the soil is fairly firm the sand-barrel, Fig. 3, is a valuable expedient. This consists of a strong barrel or barrels placed at the bottom of the hole into which the pole is set. The barrel is filled with a firm substantial soil. By this means the pole is given a larger bearing area. Sometimes a temporary sand-barrel is used consisting of a special iron cylinder that is placed around the pole filled with firm dirt and then hoisted away.

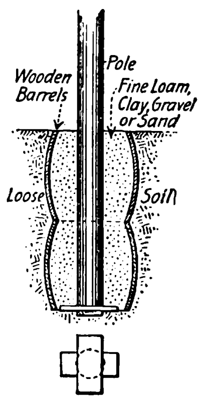


FIG. 3.—Sand barrel.

Where the soil is quite weak it is customary to use a base of concrete, Fig. 4A. A suitable mixture is one part cement, three parts of sand and three parts of broken stone or coarse gravel. Another expedient, Fig. 4B, consists in bolting transversely to the butt of the pole one or more logs some 6 or 7 ft. in length. This provides an additional bearing area that in many cases will be sufficient to support the pole. In marshy ground a more elaborate foundation (Fig. 4, C and D) is often necessary, and is made by building a wooden foundation to support the pole.

17. **When setting poles in rock** the hole may be blasted, or a hole $1\frac{1}{2}$ in. in diameter may be drilled in the rock (Fig. 5) into which an iron pin is placed that extends about 6 in. above the surface. A similar hole is drilled in the butt of the pole, and the pole mounted on the pin. It must then be braced by three or four wood struts spiked to the pole 6 ft. from the ground, running diagonally to the rock and formed thereto, or by guy wires made fast to metal pins set in the rock.

18. **Setting Poles with a Gin-pole.**—A few men can set a large pole with a "gin-pole" as suggested in Fig. 6. The gin-pole can be a short wooden pole or, where the poles to be raised are not too heavy, a length of wrought-iron pipe. The "gin" need be only $\frac{1}{2}$ as long as the pole to be raised. In setting a pole the "gin" is first raised to an almost vertical position with its top over the pole hole. It is held in that position by fastening the guy lines. Then the hook of the tackle blocks is engaged in a sling around the pole and the pole is raised, by men or by a team of horses, by pulling on the free end of the tackle block line. When high enough that its lower end can be slipped into it, the pole is dropped into the hole, adjusted to a vertical position with pikes and the earth is tamped in. Sometimes "gin-poles" are permanently mounted

on wagons for transportation and are then called **pole derricks.** They are great savers of time and money.

19. Resetting Poles.—When a pole becomes old and rotten at its butt it can be reset if the expense of a new pole is not justified. In resetting, the pole is temporarily sustained with 3 or 4 pole pikes

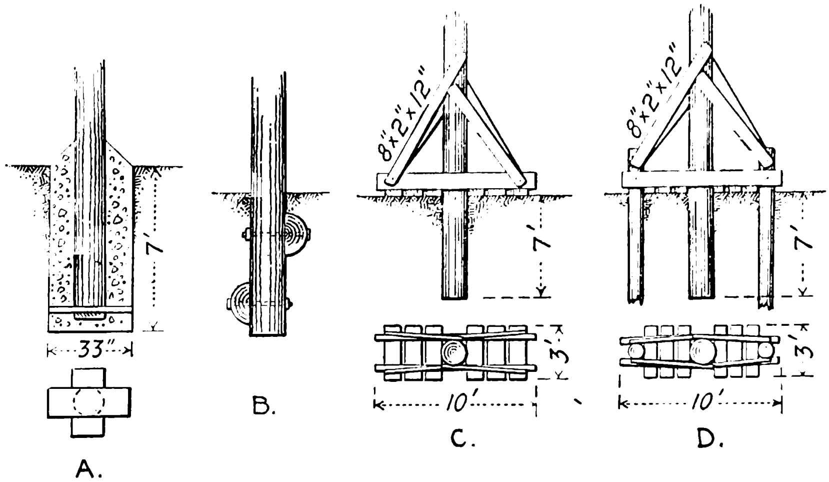
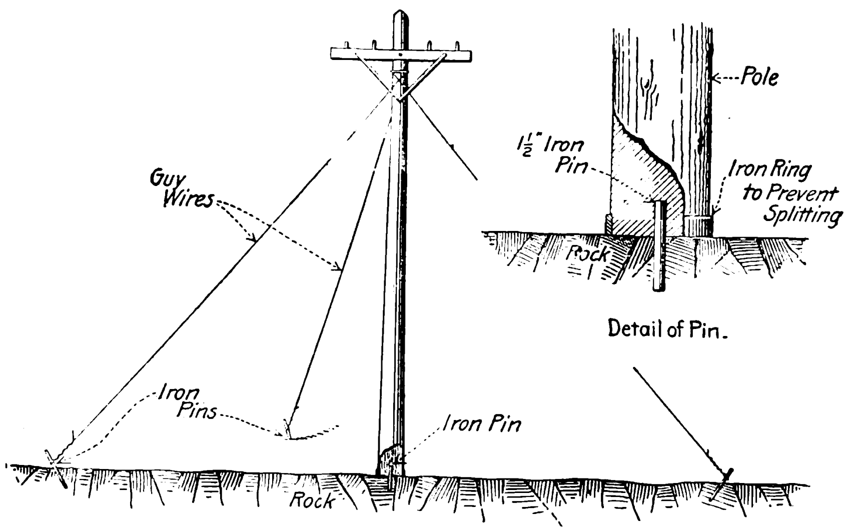


FIG. 4.—Methods of setting poles in poor soils.



Method of Guying Pole.

FIG. 5.—Method of setting pole on rock.

and chopped off just above the ground line. Then the lower end of the portion of the pole above ground line is set to one side and the butt in the ground dug out and thrown away. The lower end of the upper portion of the pole is then dropped into the hole. A reset pole is as many feet shorter than it formerly was as its butt

was set feet in the ground. Sometimes the hole is dug around the butt before the pole is chopped off. The method of reinforcing with concrete and steel described in 20 is usually much superior to resetting.

20. Reinforcing Old Poles with Concrete and Steel. (*Electric Journal*, January, 1910).—Wooden poles usually become unsafe

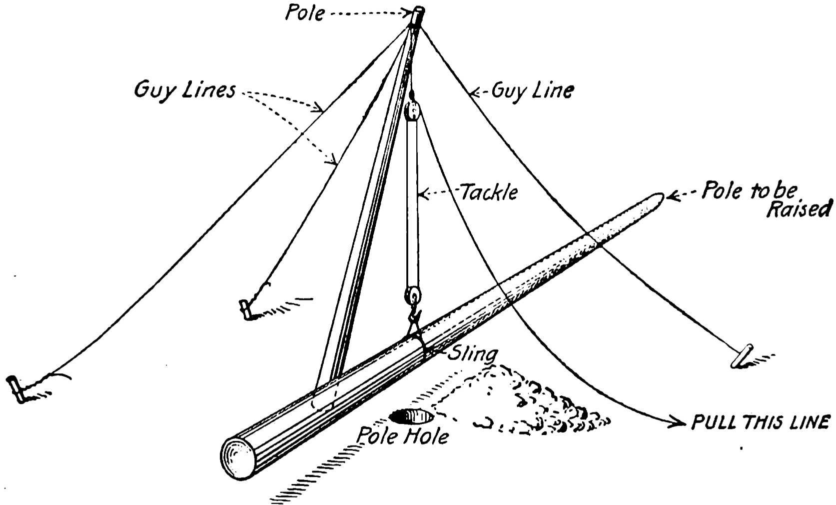


FIG. 6.—Gin-pole for raising poles.

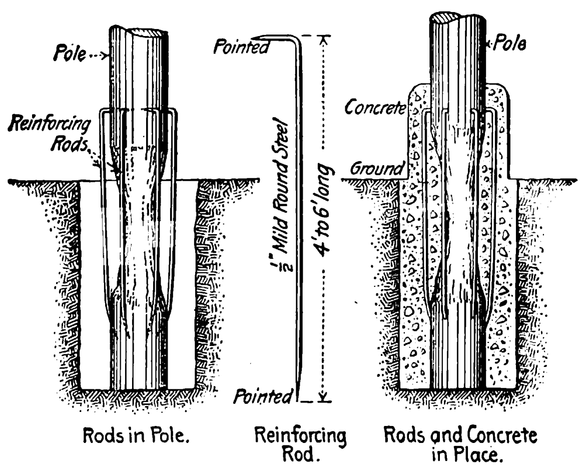


FIG. 7.—Reinforcing pole with concrete.

because of butt rot at the ground line. Such poles can be repaired without moving the wires they support by reinforcing them with steel and concrete as shown in Fig. 7. For ordinary poles and conditions, 10 mild steel rods ½ in. in diameter and 4 ft. to 6 ft. long are used for reinforcing. The lower end of each reinforcing rod is pointed and is driven into the portion of the butt that remains in the hole. The other end is bent at right angles, and

pointed. It is driven into the pole above the ground line. A 1–2½–5 mixture of concrete is used for the main body and a richer mixture is used for the portion above ground line and is molded in a cylindrical sheet-iron form. The concrete extends to about 1½ ft. above the ground line. Poles 15 to 20 years old have been satisfactorily repaired by this method without moving the wires

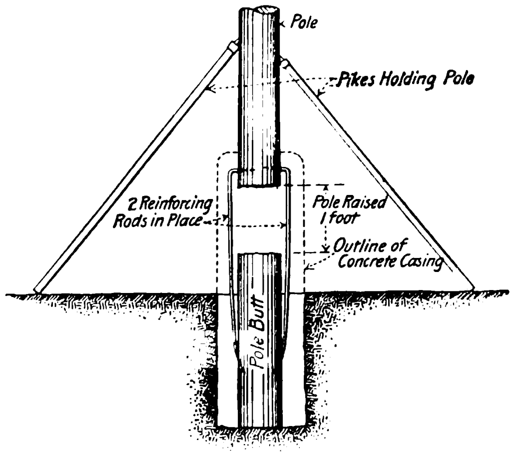


FIG. 8.—Raising and reinforcing a wooden pole.

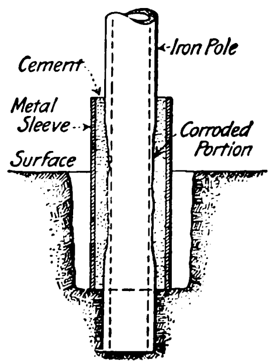


FIG. 9.—Repairing metal pole.

supported. Poles have been raised 12 in. and then reinforced as shown in Fig. 8, and this without moving a cross-arm or fixture on the pole.

21. **The cost of concrete and steel reinforcing** is said to average about $3.50 per pole and is always less than the cost of replacement. It is stated that ordinary poles reinforced by this method are capable of withstanding a horizontal strain of 1,000

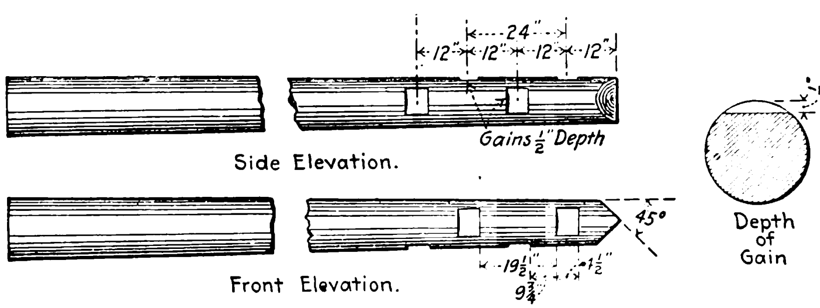


FIG. 10.—Gains in pole.

lbs. applied 27 ft. above the ground line. The reinforcement can be made almost as strong as one pleases by using more concrete and rods. The method is patented.

22. **Repairing Steel Poles.**—Metal poles sometimes corrode very rapidly at the ground and often when discovered the corrosion is too far advanced to make any preventive measures effective. A very satisfactory method (Fig. 9) of repairing steel poles is to

place a loose-fitting metal sleeve around the butt of the pole and fill the space between the two with Portland cement.

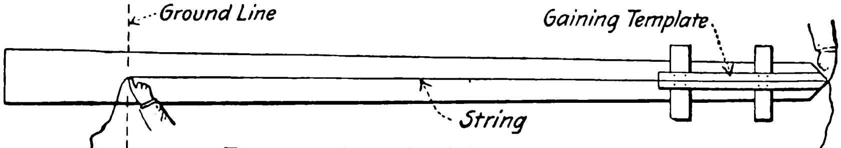


FIG. 11.—Use of gaining template.

23. Poles are gained or framed as shown in Figs. 10, 11 and 12. The gaining templet of Fig. 13 is convenient in laying out the gains. The gain should be exactly the width of the cross-arm

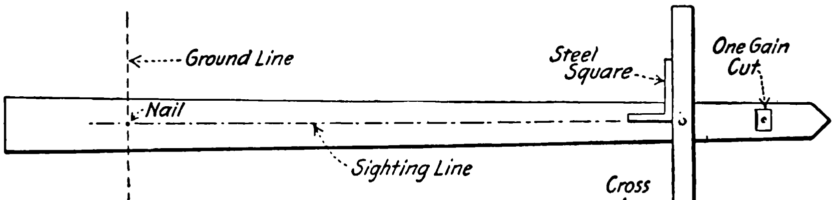
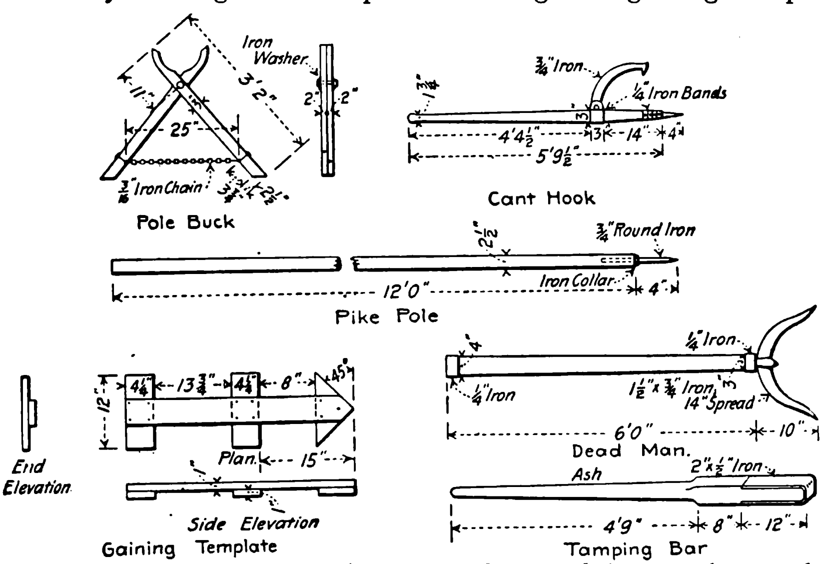


FIG. 12.—Locating gain with steel square and cross-arm.

insuring a snug fit. In good work gains should always be spaced on 24-in. centers and should be ½ in. deep. Nothing is accomplished by making them deeper. In using the gaining templet



Note.—The tool illustrated above as a *Cant-Hook* is properly termed a *Peavie*. A peavie has a splice in the end of its handle, while a cant-hook has no splice.

FIG. 13.—Some line-construction tools.

(Fig. 11) the point of the "roof" of the templet is placed exactly over the point of the roof of the pole and the templet is shifted until its center line (which should be marked thereon) lies exactly

under a cord stretched from the roof point to the center of the pole, at the ground line. Then the positions of the cross-arm gains are indicated by knife scratches made along the sides of the cross pieces on the templet.

Where a gaining templet is not available a cross-arm (Fig. 12) can be laid on the pole with a steel square held against its lower face, the outer edge of the short limb of the square lying at the center of the pole and the center of the cross-arm. Rotate the cross-arm in a horizontal plane until, by sighting, it is evident that the edge of the square coincides with an imaginary center line to a nail in the center of the butt at the ground line. Indicate the gain location by knife scratches along the cross-arm sides.

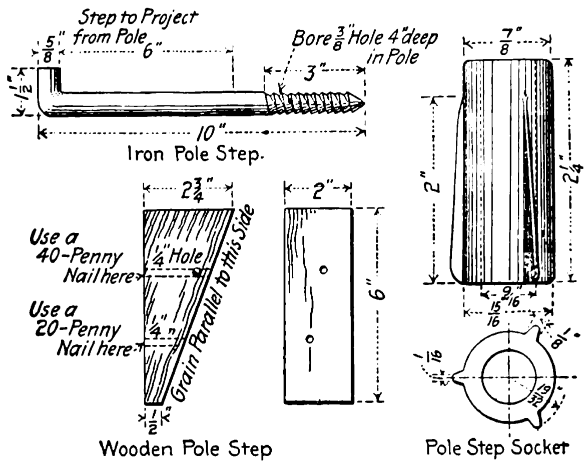


FIG. 14.—Pole steps and socket.

24. Pole steps (Fig. 14) can be located on the pole as shown in Fig. 15. A $\frac{3}{8}$-in. hole 4 in. deep is bored for the iron step. It is driven into the hole until it projects 6 in. from the pole and is then turned with a wrench until the hook end is vertical. The wooden step is held to the pole with one 40-penny and one 20-penny nail or with cut spikes. Often the wooden steps are omitted. The lowest iron step should be at least 7 ft. from the ground. Pole steps should extend from the pole in the same direction as that of the street on which the pole is set.

25. Pole step sockets, Fig. 14, are sometimes substituted for the wooden steps. The sockets drive into a $\frac{7}{8}$-in. hole. To climb the pole a lineman can temporarily insert bolts or similar pieces of metal into the sockets.

26. Pole braces are used where guying is not feasible and cost more than equivalent guys. Fig. 16 shows methods of bracing poles. The upper end of each brace fits in a notch cut in the pole and is bolted thereto.

27. Guying.—Probably there are not as many guys on pole lines as there should be to insure continuity of service and minimum maintenance expense. Lines should be guyed not for normal conditions but for the most severe conditions that are liable to

obtain. The guys should be frequent and heavy enough to sustain the line after the heaviest snow storm or during the worst possible wind storm. A guy should be used on every pole where the tension of the wires tends to pull the pole from its normal position.

Terminal poles should always be head guyed and on lines carrying three or more cross-arms, the two poles next to the terminal pole should also be head guyed to distribute the stress.

Line guys are installed on straight pole lines to reinforce them against the excess stresses introduced by storms. It is good practice to install head line guys, as shown in Fig. 17, at about every twentieth pole. This applies only to lines carrying more than one cross-arm.

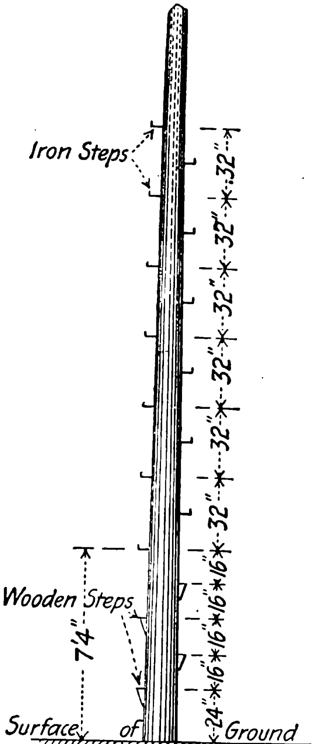


Fig. 15.—Location of pole steps on pole.

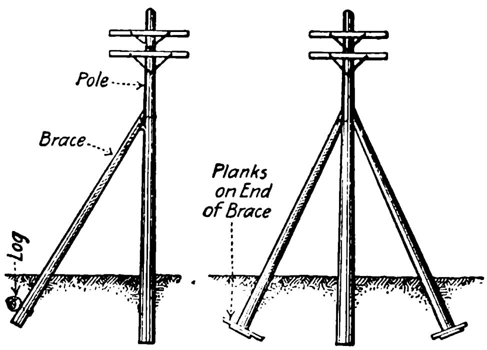


Fig. 16.—Bracing poles.

The installation of additional side guys, arranged at right angles to the line, to trees, stubs or anchors, is recommended. The side guys are attached to the same pole as the head guys.

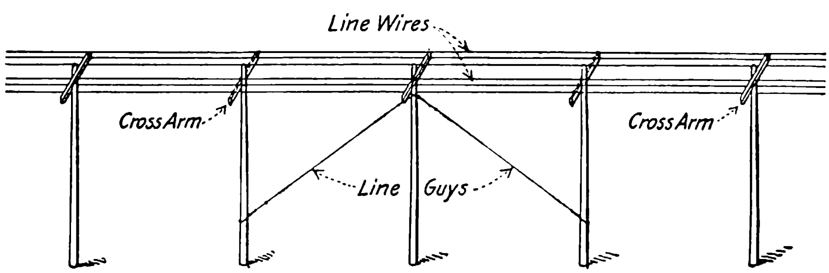


Fig. 17.—Line guys.

Side guys should be installed at curves, the guys taking the direction of radii of the curves. Fig. 2 shows a table that gives the number of side guys required for a given line with a given "pull." The pull is the distance from the pole to a line joining

two points in the line 100 ft. on either side of the pole. See the illustration, Fig. 2.

POLES ON EITHER SIDE OF A LONG SPAN should be head guyed as shown in Fig. 18.

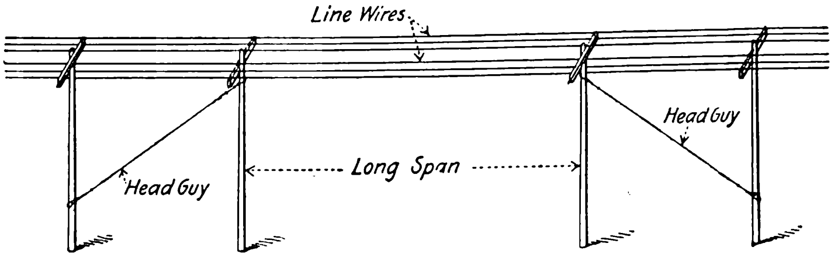


FIG. 18.—Head guys for a long span.

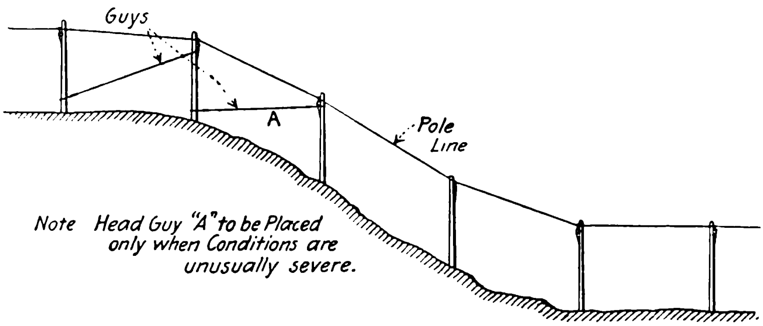


FIG. 19.—Head guys at a steep hill.

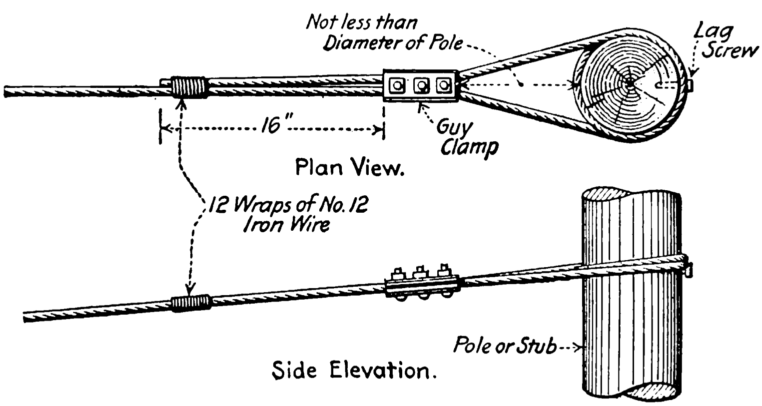


FIG. 20.—Guy attachment to pole or stub.

LINES ON STEEP HILLS SHOULD BE GUYED as shown in Fig. 19 with head guys.

GUY WIRES SHOULD BE KEPT MORE THAN 8 FT. FROM THE GROUND where possible to prevent persons from making accidental contact with them. A clearance of at least 3 ft. should be maintained between

guys and electric wires, otherwise changes in temperature may cause the wires to come in contact.

28. The method of making up a guy on a pole or stub is shown in Fig. 20. Galvanized iron plates called pole plates are sometimes used on soft poles, on cedar poles particularly, under the guy wire to prevent it from cutting into the pole. These plates are about $\frac{1}{16}$ in. thick, 3 in. wide and 5 in. long. Where there is but one guy per pole, it is made up around the pole just under the top cross-arm as shown in Figs. 21 and 22. Where there are two guys to the pole, one is made up just under the top cross-arm and one just under the bottom cross-arm. Where more than two guys are used, the additional ones should be spaced as equally as possible between the top and the bottom guys that are made up under the top and bottom cross-arms respectively. Where there are two or more guys to a pole, each should be independent of the others. The different guy wires should not cross one another. Where two or more guys support a pole, a turn buckle should be inserted in all but one to equalize the stresses.

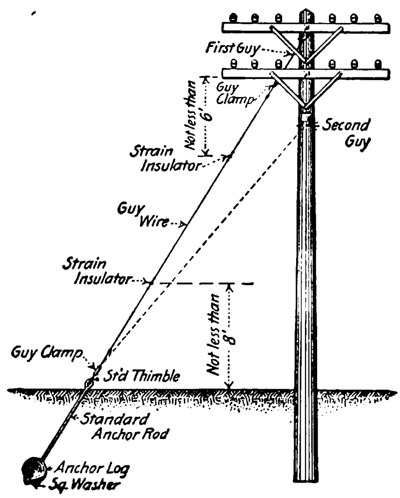


FIG. 21.—An anchor-guyed pole.

29. The method of installing an anchor guy is shown in Figs. 23 and 25. A guy rod and washer are shown in Fig. 24. The eye

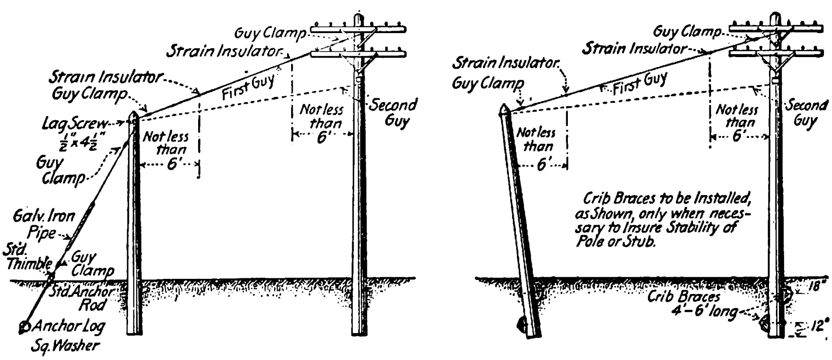


FIG. 22.—Poles guyed to stubs.

of the guy rod should extend about 1 ft. above the surface of the earth. Guy rods should not be installed where they will interfere with traffic. An "anchor shield" of $2\frac{1}{2}$-in. or 3-in. galvanized iron pipe extending to about 8 ft. above the ground should be placed over anchor guy wires near roadways as shown in Fig. 22. The foot of an anchor guy should be as far away from the foot of the

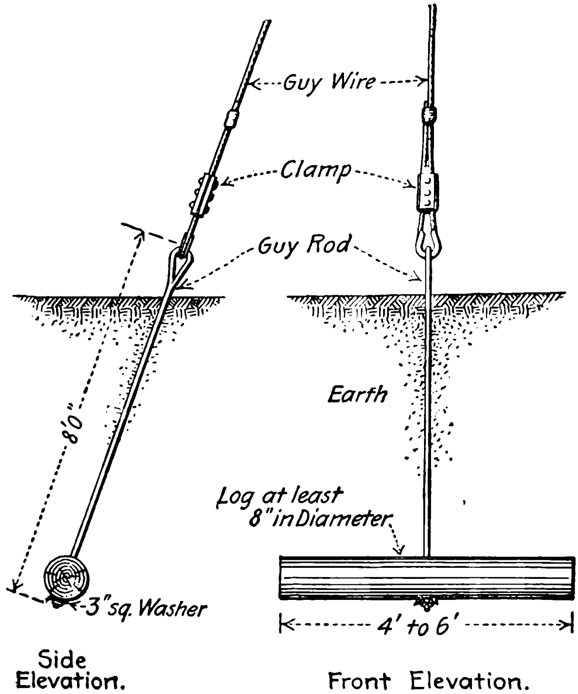


FIG. 23.—A guy rod and anchor.

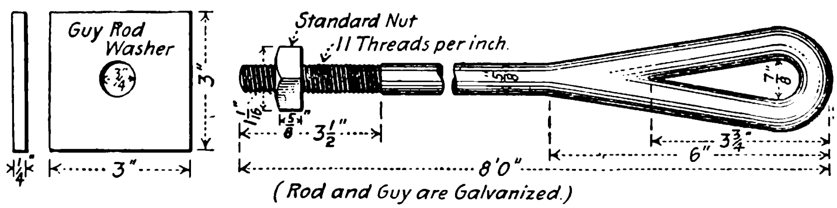


FIG. 24.—Guy rod and washer.

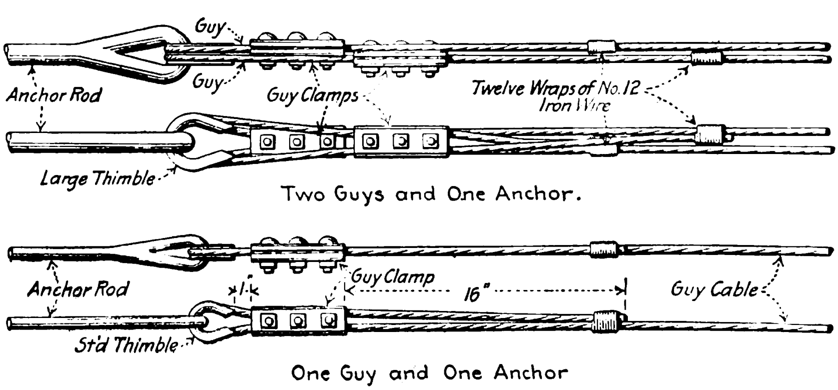


FIG. 25.—Methods of making up guys on guy rods.

pole as possible—at least a distance equal to ¼ the height of the pole.

30. **The methods of installing stub guys** are shown in Fig. 22. The stubs should be long enough that the guy wires will clear roadways by at least 18 ft., side walks by 12 ft. and electric wires by 3 ft. Stubs are used only when a line cannot be guyed properly

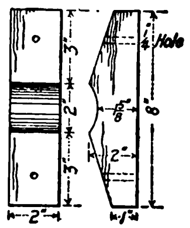


FIG. 26.—Details of tree-blocks.

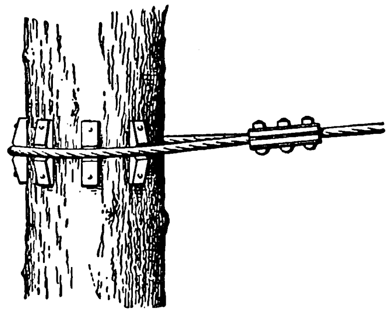


FIG. 27.—Guy wire fastened to tree.

to trees or poles. Stubs should satisfy the specifications of 2 for poles.

31. **In guying to a tree,** tree blocks (Figs. 26 and 27) should be used and the wire should pass but once around the tree. Tree guying is undesirable and should not be done unless absolutely necessary. Guys should preferably be attached to trunks or to limbs that are not less than 8 in. in diameter. Do not attach to a

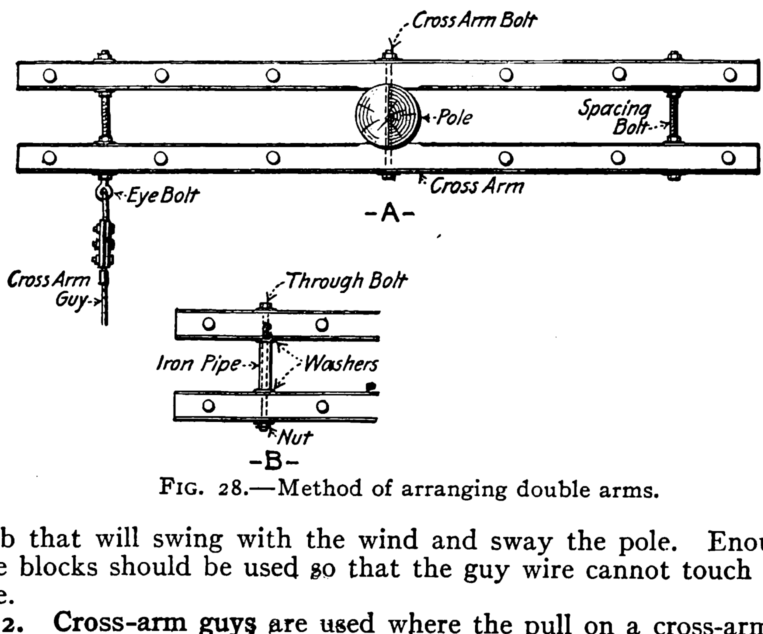


FIG. 28.—Method of arranging double arms.

limb that will swing with the wind and sway the pole. Enough tree blocks should be used so that the guy wire cannot touch the tree.

32. **Cross-arm guys** are used where the pull on a cross-arm is unbalanced. Figs. 28, 29 and 30 show examples. Cross-arm guys

usually extend from the arm to a pole or stub but sometimes for light strains the Y or "bridle" guy (Fig. 31) is used.

33. A line must be thoroughly guyed where it crosses a road. Figs. 32 and 33 show two methods of holding a line at such a point.

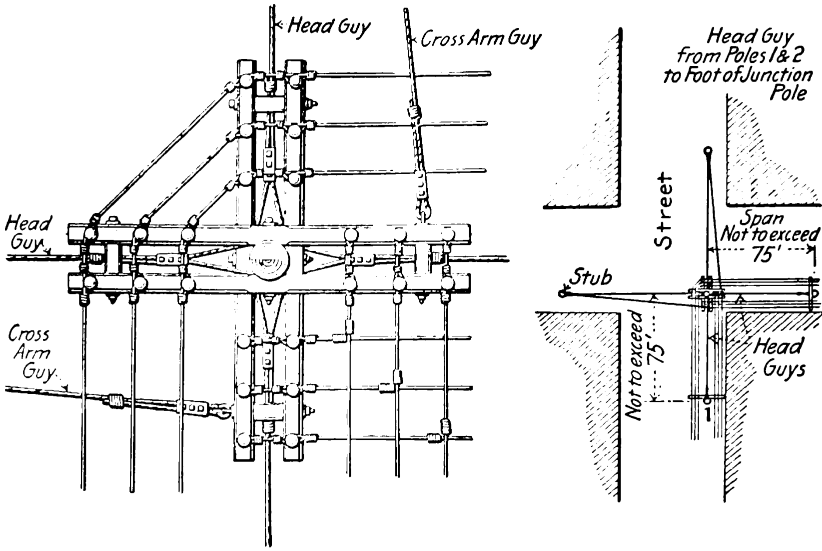


FIG. 29.—Method of turning corner with one pole.

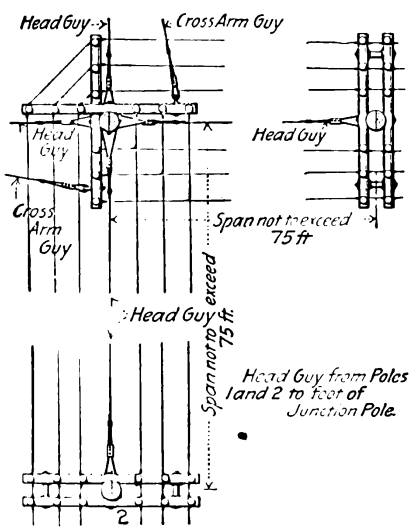


FIG. 30.—Corner pole without double arms.

The method involving the use of side guys is preferable, but the other one will give good service where side guys cannot be installed.

34. Guy-Wire Insulation.—Strain insulators should be inserted in all guy wires to poles carrying electric lighting or power wires.

Two insulators should be inserted in each guy. One is located at least 6 ft. from the pole itself or 6 ft. below the lowest line wire. The other is located at least 6 ft. from the lower end of the guy and at least 8 ft. from the ground. The two strain insulators are

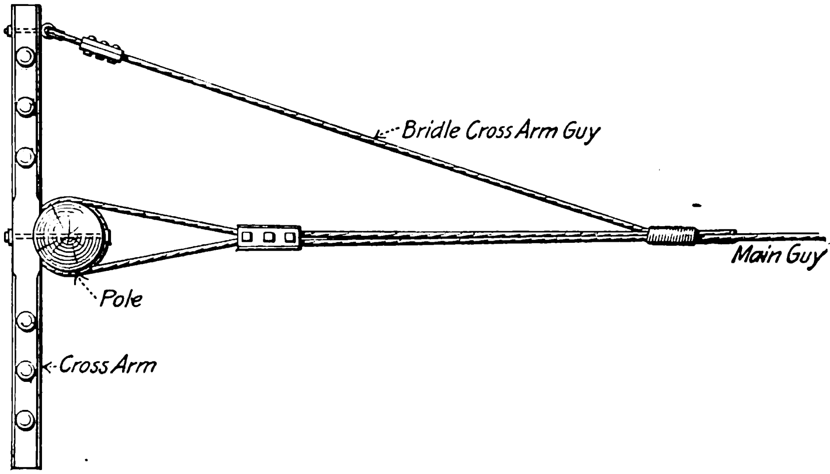


FIG. 31.—Bridle guy.

sometimes coupled in series in short guys. Wooden tree blocks (Fig. 26) are used for insulation under guys attached to iron poles.

35. **Strain insulators** are used in guys as shown in illustrations in this section and are also used in line wires at dead ending points.

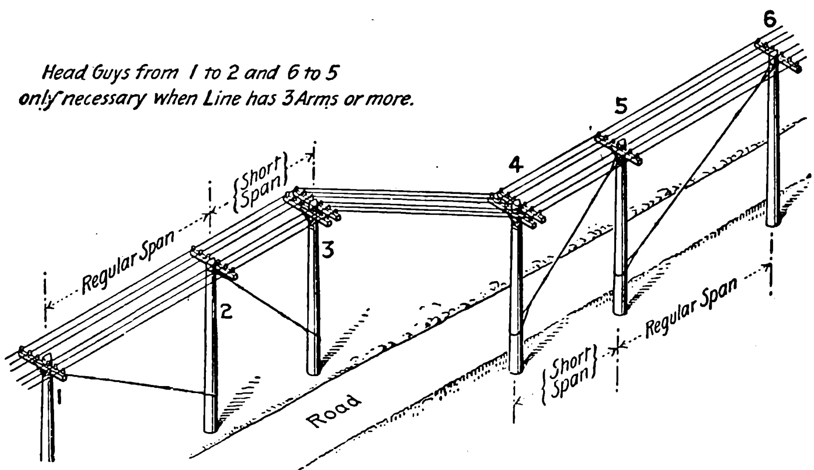


FIG. 32.—Guying at road crossing without side guys.

Composition, porcelain and wooden strain insulators are made. Wooden strain insulators (Fig. 34) are popular with some companies and afford excellent insulation but have the objection that if one burns, the wires that it supports fall. Composition and porcelain strain insulators can be made so that even if the insulating material

fails, the supported wires will not fall. Figs. 35 and 36 show types meeting these requirements. The strain insulator of Fig. 35 is cheap and satisfactory and has lately become very popular in electric lighting line construction.

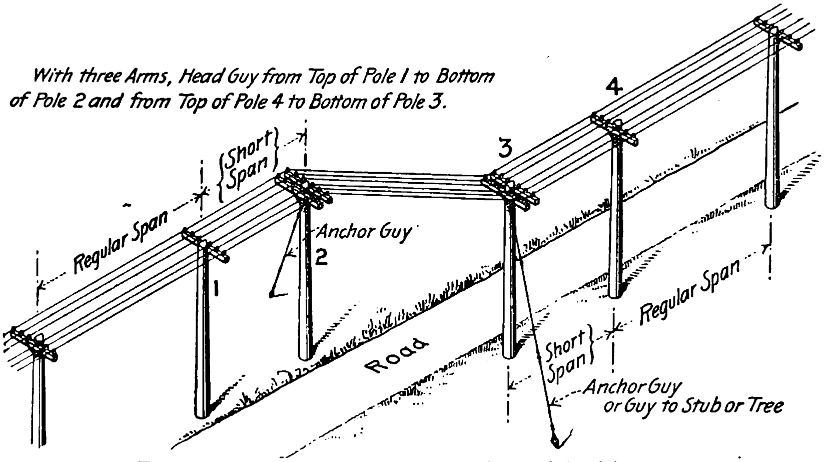


FIG. 33.—Guying at road crossing with side guys.

36. Emergency strain insulators can be made by knocking the ends out of common glass line wire insulators as illustrated in Fig. 37. To break out the end, hold the insulator in one hand

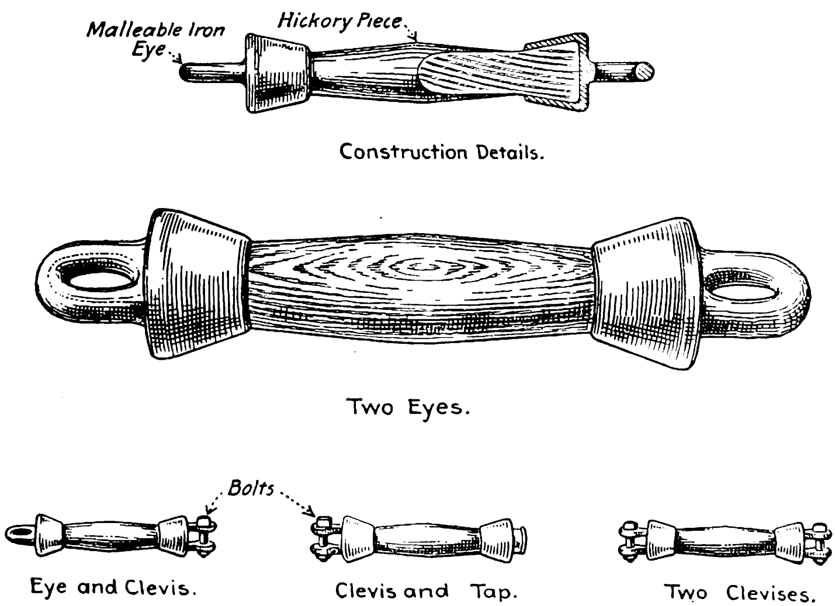


FIG. 34.—Wooden strain insulators.

and strike the inside of the top a sharp blow with the handle of a pair of plyers or of a pair of connectors or with a screw driver held in the other hand. Where one emergency insulator will not give

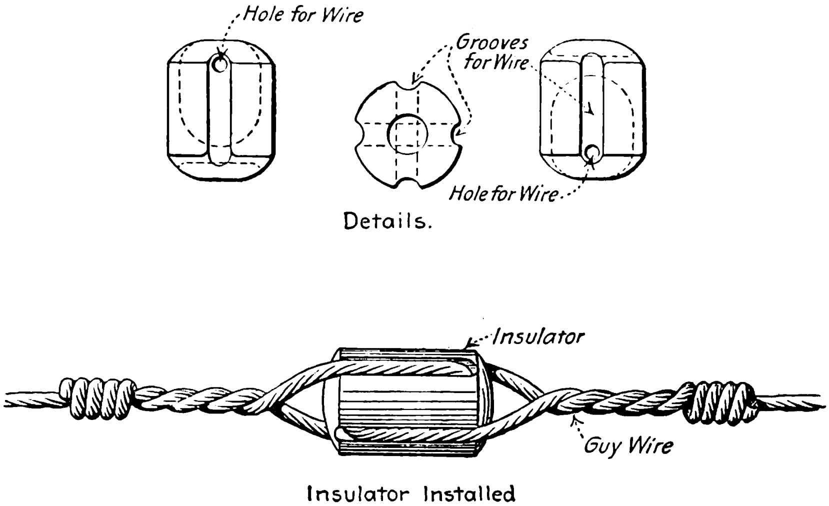


FIG. 35.—A strain porcelain insulator.

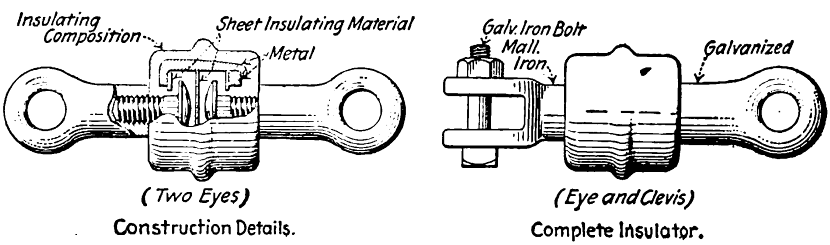


FIG. 36.—Composition strain insulators.

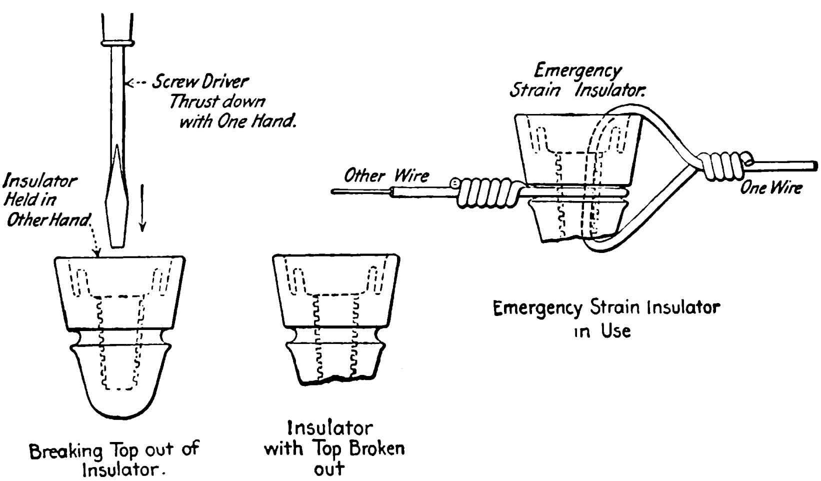


FIG. 37.—Emergency strain insulators.

sufficient insulation, two or more can be used in series. Emergency strain insulators thus made are not strong enough for heavy guy wires but are more suitable for insertion in line wires.

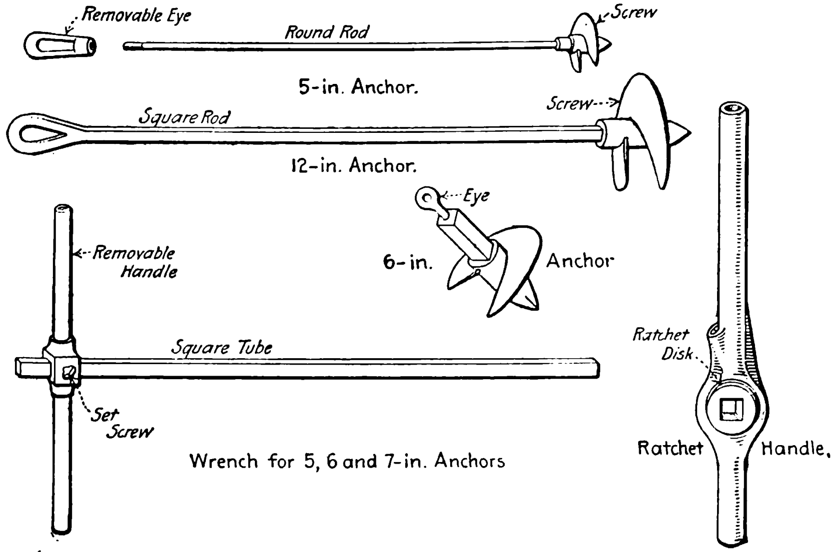


FIG. 38.—Matthew's anchors and wrenches.

37. Patented guy anchors can be used in certain kinds of soil very effectively. Fig. 38 shows one kind of anchor that is screwed into the earth with a wrench. The resistance of this sort of an anchor to withdrawal is not measured by the weight of a column

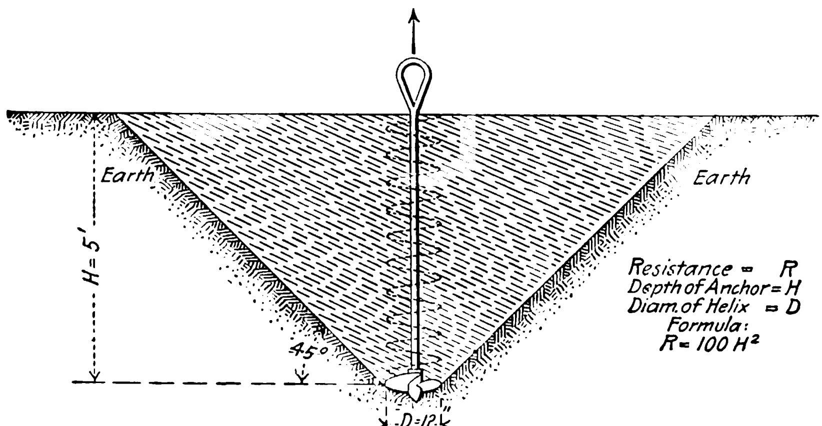


FIG. 39.—Illustrating resistance of Matthew's anchor to withdrawal.

of earth the diameter of the anchor screw, but is measured by that of a cone with sides slanting at 45° and having the point of the anchor as an apex. Fig. 39 illustrates this and shows the formula used for computing the withdrawal resistance. Fig. 39 shows the

anchor inserted perpendicularly, but an anchor should always be inserted at the same angle that the guy wire assumes, so the rod of the anchor will be in a direct line with the guy wire. Table 38 gives the actual resistances to withdrawal of the anchors.

38. Pounds Tension Required to Pull Out Matthews Guy Anchors

At Various Depths According to Prof. Carpenter's Formula (see Formula on Diagram Fig. 39).

Depth in feet	Holding Strain in Pounds					
	5 in.*	6 in.*	7 in.*	8 in.†	10 in.†	12 inch†
	lb.	lb.	lb.	lb.	lb.	lb.
3½	6,125	7,350	8,575	....	....	....
4	8 000	9,600	11,200	12,800	16,000	19,200
4½	10,125	12,150	14,175	16,200	20,250	24,300
5	12,500	15,000	17,500	20,000	25,000	30,000
5½	15,125	18,150	21,175	24,200	30,250	36,000
6	....	....	....	28 800	36,000	43,200
7	....	....	....	39 200	49,000	58,800
8	....	....	....	51,200	64,000	76,800
9	....	....	....	64,800	81,000	97,200
10	....	....	....	80,000	100,000	120,000

39. Directions for Installing Matthews Guy Anchors. 5-, 6-, AND 7-IN. WITH RODS.—Remove the eye of the anchor; pass the rod through the wrench and replace the eye, which will serve to hold the wrench rigidly to the anchor, then screw the anchor in, at the same angle as the guy wire is to run, as far as ground conditions will permit. When in as far as possible, remove the eye and pull out the wrench. Then replace the eye, thus making anchor ready for guy wire. The handle bars of the wrench are adjustable and held in place with a set screw. They can be moved back as the anchor screws in.

8-, 10-, 12-IN. WITH RODS.—Place bar or other lever in eye of anchor and screw it in as far as ground conditions will permit, always at the angle that the guy wire is to run. Time will be saved and the anchor start easier if a few spades of earth are removed before starting anchor. When the anchor is set, attach the guy strand to the eye. Always pull anchor back as far as possible before finally tying the guy wire.

NOTE.—If conditions are such that many anchors must be installed close to buildings, fences, etc., a rachet wrench should be used.

IN DRY, HARD GROUND.—In setting all anchors in hard ground, the work will be much easier if a hole is made with a digging or crow bar or a wood auger with a long shank. This makes the path of the anchor easier. A little water poured down this hole before starting the anchor will help considerably where the ground

*It is impractical to install the 5- and 6-in. anchors at a greater depth than 5½ ft.

†The 8-, 10- and 12-in. anchors will not bear a great strain at a lesser depth than 4 ft.

is hard and dry. In installing 8-, 10-, and 12-in. anchors in very hard ground, clamp a lever to the rod by means of a chain, a foot or so above the ground. As the anchor is screwed down the lever can be moved up. The anchor will start easier if a few spades full of earth are removed at the angle desired to set the guy. If a man stands on the helix of the anchor when starting until the point bites the ground it will assist.

In localities where loose gravel or small flat rock occurs, drill a hole with a digging bar or crowbar, as suggested above. If a small rock is encountered it can be broken by the bar. If a large rock is "discovered," the bar can be removed and the hole drilled in another place. This will allow the use of anchors in many places where it would seem impossible to install them.

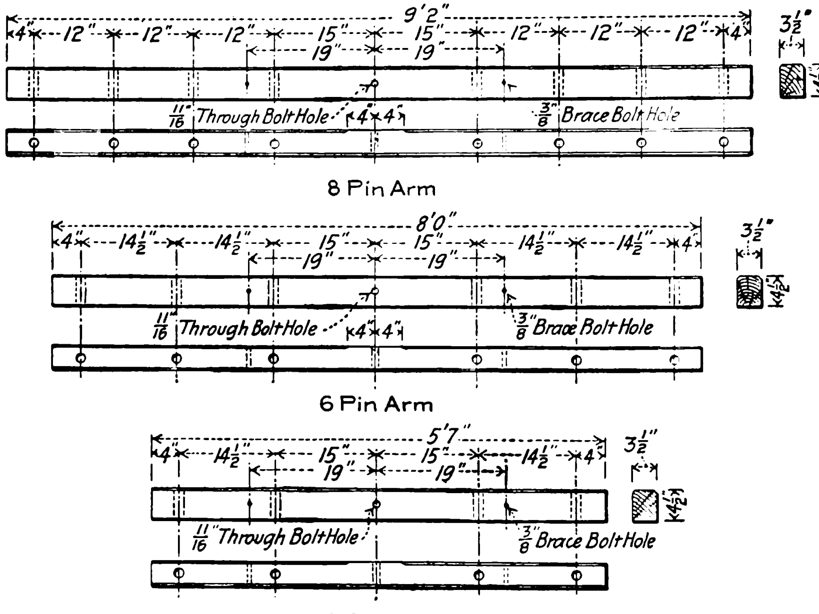


FIG. 40.—Cross-arm dimensions recommended by the N. E. L. A.

40. Guy Wire and Cable.—For unimportant work where strains are not heavy, a single strand of No. 4 or No. 6 galvanized steel wire is sometimes used (see index for table) but modern practice favors galvanized steel cable or "strand." (See index for table.) For cross-arms and other light guying, a $\frac{1}{4}$-in. steel cable (tensile strength 2,300 lb.) can be applied. The standard guy for regular pole guying is a $\frac{5}{16}$-in. special steel cable which should have a tensile strength of at least 6,000 lb. Many telephone lighting and power companies use this size and grade.

41. Cross-arms.—Table 43 shows the dimensions of the so-called standard arms. Fig. 40 shows the dimensions of cross-arms recommended by the National Electric Light Association. These arms have a spacing between center pins of 30 in., which is believed

to provide a safe climbing space. Cross-arms are best made of long-leaf yellow pine, Norway pine, or Oregon fir. Cross-arm dimensions have not actually been standardized throughout the country. It is probable that arms of the N. E. L. A. dimensions (Fig. 40) will come into extensive use. It is modern practice not to paint cross-arms as soon as they are made. They are either treated with a wood preservative or are permitted to season naturally for at least three months and are then painted with two coats of green white-lead paint before erection. No cross-arm having a spacing of less than 20 in. between center pins or $10\frac{1}{2}$ in. between side pins should be used. The six-pin arm (Fig. 40) is recommended for general use.

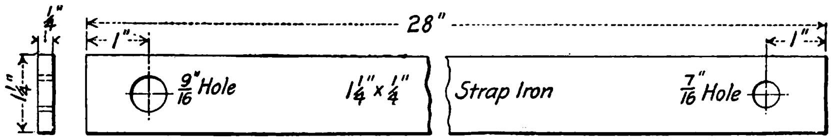


FIG. 41.—Cross-arm brace, N. E. L. A. recommendations.

42. **Cross-arm bolts** are standard $\frac{5}{8}$-in. machine bolts preferably galvanized (Fig. 42). A square washer (Fig. 42) is used under both head and nut.

43. **Standard Cross-arms.** Finished size, $3\frac{1}{4}$ in. by $4\frac{1}{4}$ in. Bored for $1\frac{1}{2}$-in. or $1\frac{1}{4}$-in. pins, two $\frac{3}{8}$-in. carriage bolts and one $\frac{5}{8}$-in. or two $\frac{1}{2}$-in. bolts, as may be directed. Pin holes shall be a driving fit; carriage bolt holes $\frac{7}{16}$ in. diameter; $\frac{1}{2}$-in. machine bolt holes $\frac{9}{16}$ in. diameter; $\frac{5}{8}$-in. machine bolt holes $\frac{11}{16}$ in. diameter.

Length ft.	No. pins	Pin spacing			Approximate weight, lb.
		Ends, in.	Sides, in	Centers, in.	
3	2	4	....	28	10
4	4	4	12	16	14
5	4	4	15	22	17
6	4	4	21	22	21
6	6	4	12	16	21
8	....	4	$16\frac{1}{2}$	22	28
8	....	4	12	16	28
$8\frac{1}{2}$	10	3	10	16	$29\frac{1}{2}$
10	8	4	15	22	35
10	10	4	12	16	35
10	12	4	$9\frac{5}{8}$	16	35

44. **Cross-arm braces** (Fig. 41) are of strap iron (mild steel) and are preferably galvanized. Braces are attached to the front of each cross-arm, each by a $4\frac{1}{2}$-in. carriage bolt (Fig. 42), before the arm is fastened to the pole. The head of the bolt is at the back of the arm and has a round washer (Fig. 42) under it. The nut is on the brace side. There are braces of other sizes in use but the one of Fig. 41 appears to be best suited for general work. The braces are secured to the pole by a square-head coach or lag screw (Fig. 42) usually $\frac{1}{2}$ in. by $3\frac{1}{2}$ in. Table **46** shows proportions of lag screws of other dimensions. Dimensions of lag screws furnished by thirty-five different manufacturers vary.

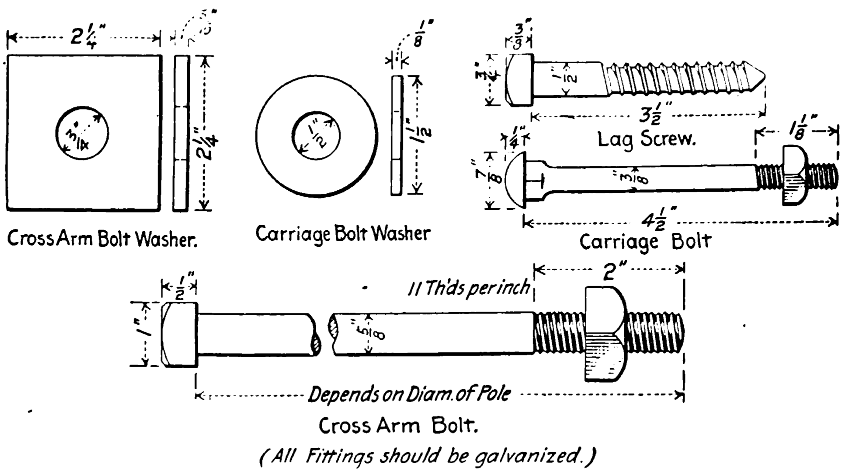


FIG. 42.—Cross-arm fittings, N. E. L. A. recommendations.

45. Dimensions of Machine Bolts and Nuts.

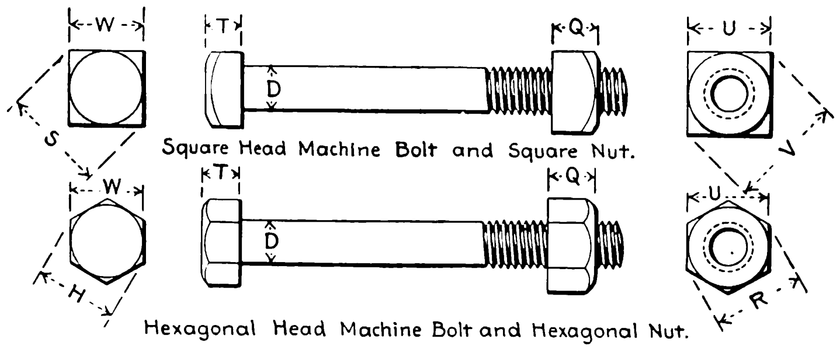


FIG. 42A.—Machine bolts and nuts.

D	T	W	S	H	Q	U	R	V
$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{17}{32}$	$\frac{7}{16}$	$\frac{3}{16}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$
$\frac{5}{16}$	$\frac{15}{64}$	$\frac{15}{32}$	$\frac{21}{32}$	$\frac{35}{64}$	$\frac{1}{4}$	$\frac{17}{32}$	$\frac{5}{8}$	$\frac{3}{4}$
$\frac{3}{8}$	$\frac{9}{32}$	$\frac{9}{16}$	$\frac{51}{64}$	$\frac{21}{32}$	$\frac{5}{16}$	$\frac{5}{8}$	$\frac{47}{64}$	$\frac{57}{64}$
$\frac{7}{16}$	$\frac{21}{64}$	$\frac{21}{32}$	$\frac{15}{16}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{23}{32}$	$\frac{27}{32}$	$1\frac{5}{64}$
$\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{16}$	$\frac{27}{32}$	$\frac{7}{16}$	$\frac{13}{16}$	$\frac{61}{64}$	$1\frac{5}{32}$
$\frac{5}{8}$	$\frac{15}{32}$	$\frac{15}{16}$	$1\frac{21}{64}$	$1\frac{5}{64}$	$\frac{9}{16}$	1	$1\frac{5}{32}$	$1\frac{27}{64}$
$\frac{3}{4}$	$\frac{9}{16}$	$1\frac{1}{8}$	$1\frac{19}{32}$	$1\frac{19}{64}$	$\frac{11}{16}$	$1\frac{3}{16}$	$1\frac{3}{8}$	$1\frac{43}{64}$
$\frac{7}{8}$	$\frac{21}{32}$	$1\frac{5}{16}$	$1\frac{55}{64}$	$1\frac{1}{2}$	$\frac{13}{16}$	$1\frac{3}{8}$	$1\frac{19}{32}$	$1\frac{61}{64}$
1	$\frac{3}{4}$	$1\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{47}{64}$	$\frac{15}{16}$	$1\frac{9}{16}$	$1\frac{11}{16}$	$2\frac{7}{32}$
$1\frac{1}{8}$	$\frac{27}{32}$	$1\frac{11}{16}$	$2\frac{25}{64}$	$1\frac{31}{32}$	$1\frac{1}{8}$	$1\frac{13}{16}$	$2\frac{3}{32}$	$2\frac{9}{16}$
$1\frac{1}{4}$	$\frac{15}{16}$	$1\frac{7}{8}$	$2\frac{21}{32}$	$2\frac{5}{32}$	$1\frac{1}{4}$	2	$2\frac{5}{16}$	$2\frac{27}{32}$
$1\frac{3}{8}$	$1\frac{1}{32}$	$2\frac{1}{16}$	$2\frac{59}{64}$	$2\frac{25}{64}$	$1\frac{3}{8}$	$2\frac{3}{16}$	$2\frac{17}{32}$	$3\frac{3}{32}$
$1\frac{1}{2}$	$1\frac{1}{8}$	$2\frac{1}{4}$	$3\frac{3}{16}$	$2\frac{19}{32}$	$1\frac{1}{2}$	$2\frac{3}{8}$	$2\frac{47}{64}$	$3\frac{3}{8}$
$1\frac{5}{8}$	$1\frac{7}{32}$	$2\frac{7}{16}$	$3\frac{3}{4}$	$2\frac{13}{16}$	$1\frac{5}{8}$	$2\frac{9}{16}$	$2\frac{31}{32}$	$3\frac{5}{8}$
$1\frac{3}{4}$	$1\frac{5}{16}$	$2\frac{5}{8}$	$3\frac{23}{32}$	$3\frac{1}{32}$	$1\frac{3}{4}$	$2\frac{3}{4}$	$3\frac{3}{16}$	$3\frac{57}{64}$
$1\frac{7}{8}$	$1\frac{13}{32}$	$2\frac{13}{16}$	$3\frac{63}{64}$	$3\frac{1}{4}$	$1\frac{7}{8}$	$2\frac{15}{16}$	$3\frac{25}{64}$	$4\frac{5}{32}$
2	$1\frac{1}{2}$	3	$4\frac{1}{4}$	$3\frac{15}{32}$	2	$3\frac{1}{8}$	$3\frac{5}{8}$	$4\frac{27}{64}$

46. Gimlet Point Square Head Coach or Lag Screw.—Lag screws $1\frac{1}{2}$ in. long and under are threaded the entire length. Lag screws longer than $1\frac{1}{2}$ in. are threaded but three-fourths of their lengths

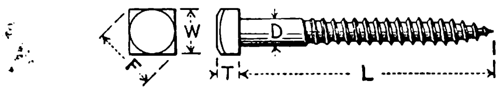


FIG. 43.—Square-head gimlet-point coach or lag screw.

D Diameter	T Thickness of head	W Width of side of head	F Distance across corners	Clearance bore for body of screw	L
$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{17}{32}$	$\frac{5}{16}$	Screws increase in length by $\frac{1}{2}$-in. increments from $1\frac{1}{2}$ in. to and including 8 in. Screws from 8 in. to 12 in. increase in length by 1-in. increments. Screws of diameters of $\frac{1}{4}$ in., $\frac{5}{16}$ in., and $\frac{3}{8}$ in. are made in lengths of $1\frac{1}{2}$ in. to and including 6 in.; $\frac{7}{16}$ in. dia. from $1\frac{1}{2}$ in. to 9 in. long; $\frac{1}{2}$ in. dia., $1\frac{1}{2}$ in. to 12 in., $\frac{9}{16}$ in. and $\frac{5}{8}$ in. dia., 2 in. to 12 in.; $\frac{3}{4}$ in. dia., $2\frac{1}{2}$ in. to 12 in.; $\frac{7}{8}$ in. dia.; 3 in. to 12 in., 1 in. dia., $3\frac{1}{2}$ in. to 12 in. long.
$\frac{5}{16}$	$\frac{15}{64}$	$\frac{15}{32}$	$\frac{21}{32}$	$\frac{3}{8}$	
$\frac{3}{8}$	$\frac{9}{32}$	$\frac{9}{16}$	$\frac{51}{64}$	$\frac{7}{16}$	
$\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{16}$	$\frac{9}{16}$	
$\frac{5}{8}$	$\frac{15}{32}$	$\frac{15}{16}$	$1\frac{21}{64}$	$\frac{11}{16}$	
$\frac{3}{4}$	$\frac{9}{16}$	$1\frac{1}{8}$	$1\frac{19}{32}$	$\frac{13}{16}$	
$\frac{7}{8}$	$\frac{21}{32}$	$1\frac{15}{16}$	$1\frac{55}{64}$	$\frac{15}{16}$	
1	$\frac{3}{4}$	$1\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{1}{16}$	

47. Common or Button Head Carriage Bolts.

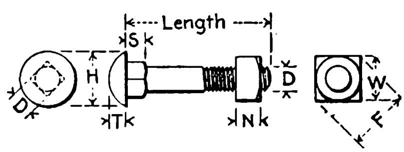


FIG. 44.—Common carriage bolt.

D Diameter, inches	Threads per inch	T Thickness of head	S Length of square part	H Diameter of head	W Width of nut	N Thickness of nut	F Across corners of nut
$\frac{1}{4}$	20	$\frac{3}{32}$	$\frac{1}{4}$	$\frac{17}{32}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{23}{32}$
$\frac{5}{16}$	18	$\frac{1}{8}$	$\frac{5}{16}$	$\frac{21}{32}$	$\frac{19}{32}$	$\frac{5}{16}$	$\frac{27}{32}$
$\frac{3}{8}$	16	$\frac{5}{32}$	$\frac{3}{8}$	$\frac{25}{32}$	$\frac{11}{16}$	$\frac{3}{8}$	$\frac{31}{32}$
$\frac{1}{2}$	13	$\frac{7}{32}$	$\frac{1}{2}$	$1\frac{1}{32}$	$\frac{7}{8}$	$\frac{1}{2}$	$1\frac{1}{4}$
$\frac{5}{8}$	11	$\frac{9}{32}$	$\frac{5}{8}$	$1\frac{9}{32}$	$1\frac{1}{16}$	$\frac{5}{8}$	$1\frac{1}{2}$
$\frac{3}{4}$	10	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{9}{16}$	$1\frac{1}{4}$	$\frac{3}{4}$	$1\frac{25}{32}$
$\frac{7}{8}$	9	$\frac{7}{16}$	$\frac{7}{8}$	$1\frac{13}{16}$	$1\frac{7}{16}$	$\frac{7}{8}$	$2\frac{1}{32}$
1	8	$\frac{1}{2}$	1	$2\frac{1}{16}$	$1\frac{5}{8}$	1	$2\frac{19}{64}$

48. Punched Wrought-iron Washers.

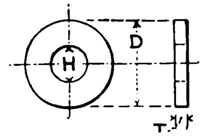


FIG. 45.—Punched wrought-iron washer.

Diam. bolt	D Outside diam.	T Approx. thick	H Diam. hole	Diam. bolt	D Outside diam.	T Approx. thick.	H Diam. hole
$\frac{3}{16}$	$\frac{9}{16}$	$\frac{3}{64}$	$\frac{1}{4}$	1	$2\frac{1}{2}$	$\frac{5}{32}$	$1\frac{1}{16}$
$\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{16}$	$\frac{5}{16}$	$1\frac{1}{8}$	$2\frac{3}{4}$	$\frac{5}{32}$	$1\frac{1}{4}$
$\frac{5}{16}$	$\frac{7}{8}$	$\frac{1}{16}$	$\frac{3}{8}$	$1\frac{1}{4}$	3	$\frac{5}{32}$	$1\frac{3}{8}$
$\frac{3}{8}$	1	$\frac{5}{61}$	$\frac{7}{16}$	$1\frac{3}{8}$	$3\frac{1}{4}$	$\frac{11}{64}$	$1\frac{1}{2}$
$\frac{7}{16}$	$1\frac{1}{4}$	$\frac{5}{64}$	$\frac{1}{2}$	$1\frac{1}{2}$	$3\frac{1}{2}$	$\frac{11}{64}$	$1\frac{5}{8}$
$\frac{1}{2}$	$1\frac{3}{8}$	$\frac{3}{32}$	$\frac{9}{16}$	$1\frac{5}{8}$	$3\frac{3}{4}$	$\frac{11}{64}$	$1\frac{3}{4}$
$\frac{9}{16}$	$1\frac{1}{2}$	$\frac{3}{32}$	$\frac{5}{8}$	$1\frac{3}{4}$	4	$\frac{11}{64}$	$1\frac{7}{8}$
$\frac{5}{8}$	$1\frac{3}{4}$	$\frac{1}{8}$	$\frac{11}{16}$	$1\frac{7}{8}$	$4\frac{1}{4}$	$\frac{11}{64}$	2
$\frac{3}{4}$	2	$\frac{1}{8}$	$\frac{13}{16}$	2	$4\frac{1}{2}$	$\frac{11}{64}$	$2\frac{1}{8}$
$\frac{7}{8}$	$2\frac{1}{4}$	$\frac{5}{32}$	$\frac{15}{16}$	....	....	....	....

49. Side arms are used (Fig. 46) in alleys and other locations where it is necessary to clear obstructions. These cross-arms are special, the dimensions are given in the illustration, and the fittings used on them are special. Side guys or crib braces (see illustration) are used where the line wires are heavy, to counteract the tendency of the pole to tip.

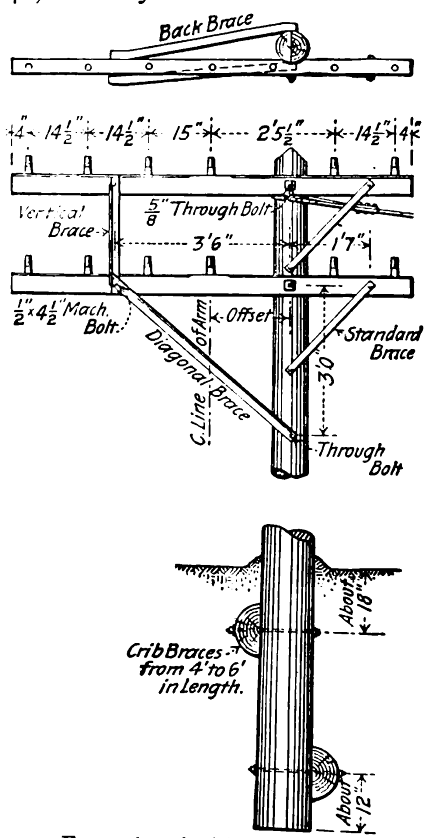


FIG. 46.—A side-arm pole.

50. Double arms are used wherever the stress on the arms is unusually severe or where every precaution is necessary to insure safety. Double arms are often used on the poles at each side of a street, at each side of railroad crossings, at corners or other points where the direction of a line changes. Figs. 28, 29, 30, 32, 33, 47, 48, and 49 show examples of double-armed poles. The two cross-arms can be separated by wooden spacing blocks, Fig. 47, by spacing bolts, Fig. 28, *A*, or by spacing nipples, Fig. 28, *B*.

The spacing blocks can be sawed from a cross-arm. A $\frac{11}{16}$-in. hole bored through the

block and cross-arm accommodates a $\frac{5}{8}$-in. bolt. A washer is used under bolt head and nut. Spreader bolts can be used instead of spacing blocks (Fig. 28, *A*); the bolts are threaded their entire lengths. A galvanized iron pipe nipple can also (Fig. 28, *B*) be used to separate the cross-arms. There is not a great deal of choice between the methods if the fittings for each are available. Probably the wooden spacing-block method is most used because the supplies required for it are always readily obtained "on the job." Where an arm guy is to be attached to the cross-arm, an eye-spreader bolt can be used as shown. Single-armed poles are now often used particularly on junction poles, as shown in the accompanying illustrations, in locations where double arms were

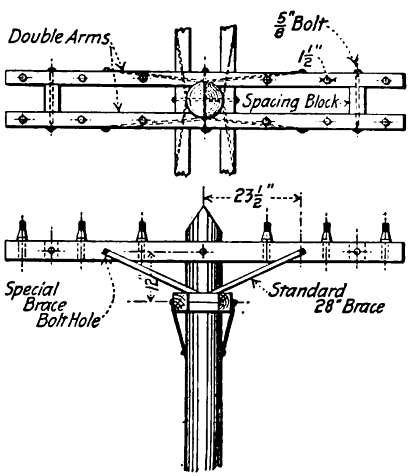


FIG. 47.—A buck-armed pole, doubled arms.

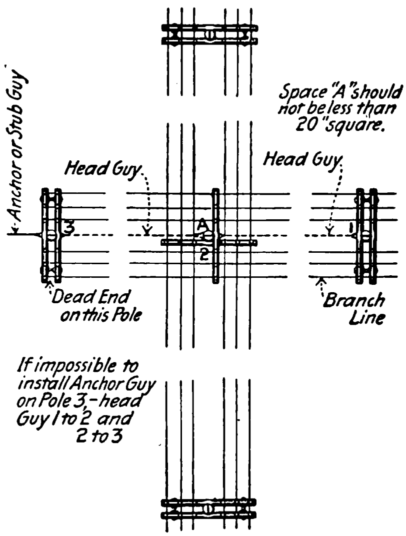


FIG. 48.—Junction pole without double arms.

formerly thought necessary. The single arms are preferable in that they allow greater climbing space for linemen.

51. Reverse or buck arms are used at corners. See Figs. 29, 30, 47 and 48. When placing buck arms, ample room must be provided through which a lineman can reach the top of the pole. A 20-in. square space is the minimum. Cross-arm braces on buck-arm poles should be attached to the arms at a point $23\frac{1}{2}$ in. from the center of arm instead of at 19 in., the standard distance for ordinary framing. The $\frac{3}{8}$-in. holes for the brace (carriage) bolts must be specially bored, at the above spacing, in buck arms. The 23-in. spacing is correct for 28-in. braces.

52. Cross-arm pins should be of locust. Oak pins are sometimes used but they are treacherous and may break when they should not and thereby cause accidents. Table **56A** and Fig. 53 show dimensions of some standard pins. The pin dimensions recommended by the National Electric Light Association for ordinary distribution use are shown in Fig. 51.

53. Pins are held in cross-arms with a six-penny nail as shown in Fig. 52. The nail should not be driven entirely in. Enough of its length should extend so that the cutting jaws of a pair of plyers can be forced under the head and the nail thereby withdrawn. If this suggestion is followed and it is necessary to remove a pin, it can be readily accomplished.

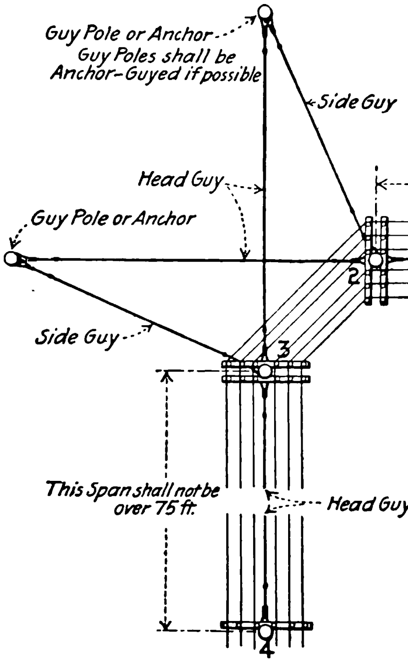


FIG. 49.—A right-angle turn.

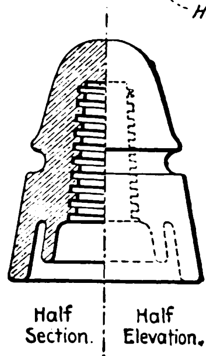


FIG. 50.—Double petticoat insulator.

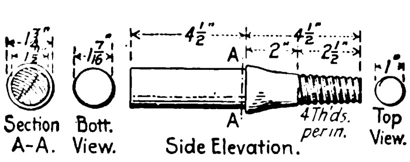


FIG. 51.—Pin recommended by the N. E. L. A.

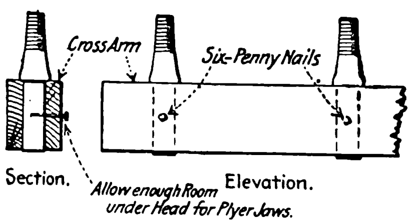


FIG. 52.—Fastening pin in cross-arm.

54. Insulators.—Glass insulators are ordinarily used for conductors at pressures of 2,200 volts and under. However, porcelain insulators are much cheaper than they once were and porcelain is now a formidable competitor of glass as an insulator material for even the lower voltages. Insulators should be of the deep-groove double-petticoat type. The insulator illustrated in Fig. 50 will give excellent service at pressures under 4,000 volts.

55. Glass insulators are cheaper than porcelain, and owing to its transparency, flaws can be detected by a simple inspection.

(*Standard Handbook.*) Glass has an exceedingly high dielectric strength and specific resistance. It condenses moisture on its surface and the action of the distilled water destroys the smoothness of the surface and allows dirt to collect and form a leakage path around the insulator.

56. Porcelain insulators give less trouble from leakage and are superior to glass in resisting constant and large changes in temperature. The surface resistance is increased by using a number of petticoats.

56A. Wooden Insulator Pins.—All standard insulator pins of 1-in. and $1\frac{3}{8}$-in. top diameter have four threads to the inch and a tapering diameter of $\frac{1}{16}$-in. increase for each inch in length.

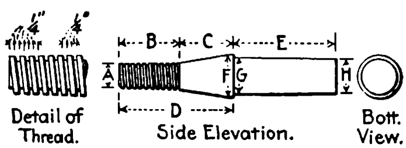


FIG. 53.—Wooden insulator pin.

Dimensions in inches								Shipping wt. per 1,000 lb.
A	B	C	D	E	F	G	H	
1	$2\frac{1}{2}$	$2\frac{1}{4}$	$4\frac{3}{4}$	$4\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{7}{16}$	400
1	$2\frac{1}{2}$	$4\frac{3}{4}$	$7\frac{1}{4}$	$4\frac{1}{4}$	2	$1\frac{1}{2}$	$1\frac{7}{16}$	510
1	$2\frac{1}{2}$	$4\frac{3}{4}$	$7\frac{1}{4}$	$4\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{11}{16}$	700
1	$2\frac{1}{2}$	4	$6\frac{1}{2}$	5	$2\frac{1}{2}$	2	$1\frac{15}{16}$	930
$1\frac{3}{8}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$4\frac{3}{4}$	$4\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$1\frac{7}{16}$	400
$1\frac{3}{8}$	$2\frac{1}{4}$	5	$7\frac{1}{4}$	$4\frac{1}{4}$	2	$1\frac{1}{2}$	$1\frac{7}{16}$	510
$1\frac{3}{8}$	$2\frac{1}{4}$	5	$7\frac{1}{4}$	$4\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{11}{16}$	700
$1\frac{3}{8}$	$2\frac{1}{4}$	$4\frac{1}{4}$	$6\frac{1}{2}$	5	$2\frac{1}{2}$	2	$1\frac{15}{16}$	930
$1\frac{3}{8}$	$2\frac{1}{4}$	$7\frac{1}{4}$	$9\frac{1}{2}$	5	3	2	$1\frac{15}{16}$	1,160
$1\frac{3}{8}$	$2\frac{1}{4}$	$8\frac{3}{4}$	11	5	$3\frac{1}{2}$	2	$1\frac{15}{16}$	1,280
$1\frac{3}{8}$	$2\frac{1}{4}$	$9\frac{3}{4}$	12	5	$3\frac{1}{2}$	2	$1\frac{15}{16}$	1,360

57. In locating circuits on poles the through wires or trunk lines should be carried on the upper cross-arms and the local wires, those which are tapped frequently should be carried on the lower cross-arms. The two or three wires of a circuit should always be carried on adjacent pins. This is of particular importance with alternating-current circuits as the inductance, consequently the inductive voltage drop, is increased as the distance between the wires of a circuit is increased. Wires of a circuit should always take the same pin positions on all poles to facilitate trouble hunting. Series circuits which do not operate during the day time may often be carried on the pole pins of a cross-arm. High-tension multiple circuits that are "hot" continuously are well placed at the ends of the arms out of the way of linemen. The neutral wire should always be in the center of a three-wire circuit. Fig. 54 shows one good arrangement on a two, four-pin-arm pole.

58. Wire and Wire Sizes for Electric Light and Power Lines.—No wire smaller than No. 6 is used in good construction for line wire. No. 8 is sometimes used for services, not more than 75 ft. long, that do not cross a street. Solid wires are often used for sizes up to and including No. 00 and cable (stranded wire) is used for larger conductors. Triple-braid weatherproof is the standard insulation of aerial line wires. Annealed or soft-drawn wire is preferable to hard-drawn because it is more readily handled and, in the sizes used, has ample tensile strength.

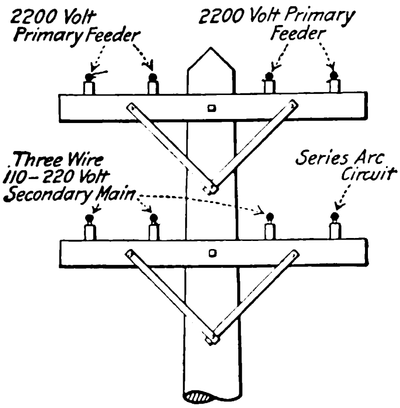


FIG. 54.—Location of circuits on a two-arm pole.

59. The perpendicular distance between all wires except where they are firmly attached to poles or other supports should be at least 24 in.

60. Clearances Required by the National Electrical Code.—The following indicates what is required for lines operating at pressures exceeding 5,000 volts. It represents, however, excellent practice for 2,000-volt lines. (The matter is taken from the Factory Mutual Insurance Company's handbook.)

When it is necessary to carry 5,000-volt lines near buildings, they must be at such height and distance from the building as not to interfere with firemen in event of fire; therefore, if within 25 ft. of a building, they must be carried at a height not less than that of the front cornice, and the height must be greater than that of the cornice as the wires come nearer to the building, in accordance with the following table:

Distance of wire from building, feet	Elevation of wire above cornice of building, feet
25	0
20	2
15	4
10	6
5	8
$2\frac{1}{2}$	9

It is evident that where the roof of the building continues nearly in line with the walls, as in Mansard roofs, the height and distance of the line must be reckoned from some part of the roof instead of from the cornice.

In order to make the intent of the above rule and its application as clear as possible, the following example is given. Fig. 55 shows in full lines a three-story building with flat roof and simple cornice overhanging about 2 ft. The poles carrying the high-pressure

wires are set just inside the curbing, say 15 ft. from the building. The cross-arm is 6 ft. long, bringing the outside wires say 3 ft. each side of the pole. Therefore the wire nearest the building is 10 ft. from the cornice, in horizontal projection.

Reference to the above table will show that under these conditions the wires must be at least 6 ft. above the cornice. If, now, the building had had a very steep-pitched roof or especially one of the Mansard type, as shown in the dotted lines in this sketch, it will be readily seen that the above arrangement would not be satisfactory, for the wires would be very liable to interfere with fighting fire in the roof. Assuming that the upper corner of the dotted roof is 5 ft. back of the edge of the main cornice, this part of the roof is 15 ft. from the nearest wire and consequently the wires must be raised 6 ft. above their previous position in order that they may be 4 ft. above the roof, as required in the above table when within 15 ft. of the building, as in this case. The cut shows very clearly to what extent the dotted Mansard roof affects the height of the pole.

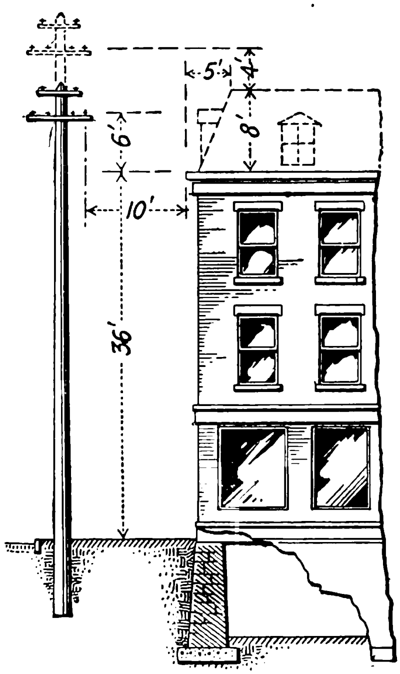


FIG. 55.—Wire location with reference to cornice.

61. Stringing Wire.—There are two methods, the choice depending on local conditions and the size and length of the circuit. By one method a reel of wire is set at one end of the line, and a rope carried 1,500 or 2,000 ft. over the cross-arms and attached to the wire that is then drawn over the arms. The other way is to place the reel on a cart, and after securing the end of the wire to the last pole the cart is started and the wire paid out till the second pole is reached, and then the wire is hoisted up and laid on the arm. Wire should always be paid out from the coil, the coil revolving, so that the wire will not be twisted. Where wire is not received on reels it should be placed on them before paying out.

62. Proper Sag in Annealed Copper Line Wires.—The wires should be pulled up until the sag equals that indicated in the following table. The permissible sag is the same for wires of all sizes and varies only with the length of span and the temperature of the air at the time of stringing the wire.

The table is based on soft-drawn copper wire, ultimate tensile strength 34,000 lb. per square inch. Triple-braided weatherproof insulation. Factor of safety, 4. Minimum temperature, −20 deg. fahr.

Span in feet	Deflection in inches						
	Temperature in degrees Fahrenheit						
	30°	40°	50°	60°	70°	80°	90°
50	8	9	9	10	11	11	12
60	10	11	11	12	13	14	14
70	11	12	13	14	15	16	17
80	13	14	15	16	17	18	19
90	14	16	17	18	19	20	21
100	16	17	19	20	21	23	24
110	18	19	21	22	24	25	26
120	19	21	23	24	26	27	28
140	22	24	26	28	30	32	33
160	26	28	30	32	34	36	38
180	29	32	34	36	39	41	43

63. Tying in Wires.—Normally the wires should rest in the insulator grooves as shown in Fig. 56, *A*, but where there is a side stress the wires should be so arranged that the pull comes against the insulators rather than away from them, Fig. 56, *B*. A single tie for the smaller wires is shown in Fig. 57, *A*, and a back tie for the larger wires is shown at *B*. The single tie wire is about 12 in. long and the back tie about 18 in. long. The back tie is made as follows: Bend the tie around the insulator under the line wire, with 4 in. on one side of the insulator and the balance on the other side. Wrap the short end three times around the line wire, leaving a space equal to the diameter of the tie wire between successive wraps.

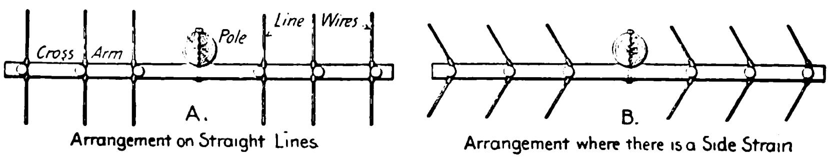


FIG. 56.—Positions of wires in insulator grooves.

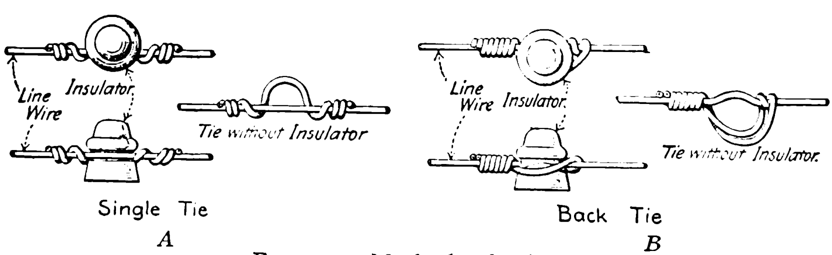


FIG. 57.—Methods of tying.

Now wrap the long end of the tie wire three times completely around the line wire, then back around the insulator and wrap it in the spaces left between the wraps of the other end of the tie wire. The ends of all tie wires should be cut off close to the line wire as shown in the illustration.

64. Tie Wires.—Tie wires should be insulated with the same material as the line wire. Do not use a tie wire twice as, after once being bent and strained, it will be brittle. The following table of sizes has been recommended for ordinary stresses. For very heavy stresses heavier tie wires should be used.

Size, line wire	Size, tie wire	Kind of tie
6	6	Single.
4	6	Single.
2	4	Single.
1	4	Back.
00 and larger	2	Back.

65. Tree Wiring.—Where wires are so carried through trees that they would rub against branches they should be supported by tree insulators of some sort or should be encased in abrasion molding. Wires should not be rigidly attached to branches or limbs because the swaying of the tree might break the wires. Fig. 58 shows some improvised tree insulators so arranged that the wires have enough play to insure against breakage. Several good patented tree insulators are on the market.

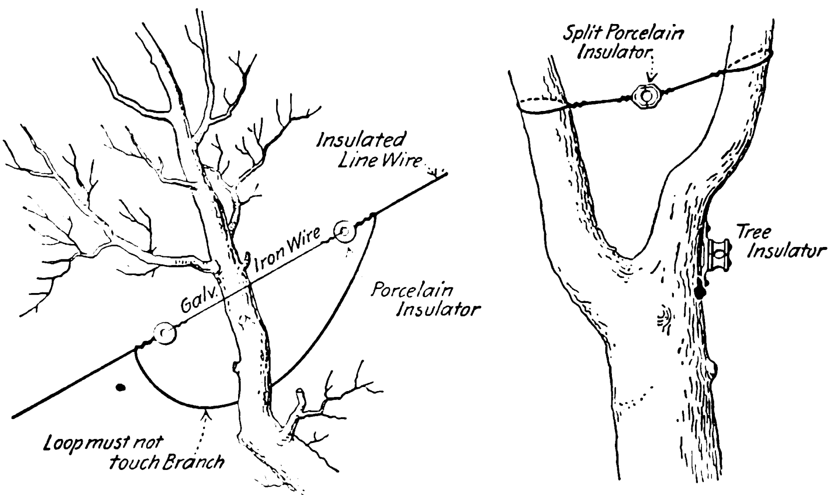


FIG. 58.—Improvised tree insulator.

66. Abrasion Molding.—Fig. 59 shows one type, made of wood, bound to the conductors with wire and taped at the ends to prevent slipping. Improvised tree moldings can be made from wooden strips nailed into the form of a box. The molding takes the brunt of the wear and prevents injury to the insulation. A length of abrasion molding should be sufficiently long that a branch cannot catch on its end.

67. Cable clamps can often be used with economy at dead-ending points and corners. Fig. 60 shows some examples. Through the use of a cable clamp the "making up" of "dead ends," which is very expensive for heavy cables, is avoided; the line wire can be

carried, without cutting, around a corner or in any new direction. The manufacturers claim, and it is probably true, that it is cheaper to purchase and install a cable clamp than to "make up a dead end" in any wire larger than No. 0000. The cable clamp grips the bare

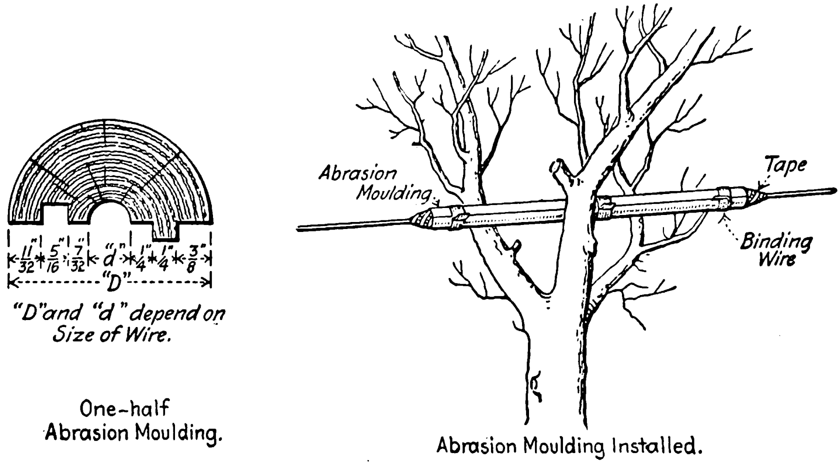


FIG 59.—Abrasion moulding.

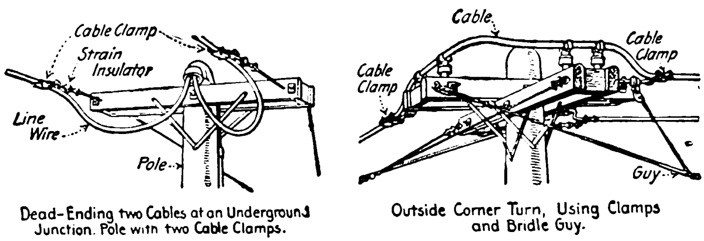


FIG. 60.—Application of cable clamp.

conductor, the pressure being furnished by four bolts. A strain insulator must be used to insulate the clamp from the bolt or turnbuckle that supports it. The dimensions of a Matthew's clamp for all wires of sizes from 000 to and including 2,000,000 cir. mils are given in Fig. 61.

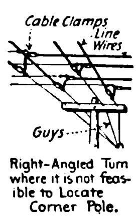


FIG. 60A.—Application of cable clamp.

68. Specification and Test for Galvanized Iron and Steel for Line Construction.—The galvanizing shall consist of a coating of zinc, evenly and uniformly applied. The zinc shall be so applied that it will adhere to the surface of the iron or steel. The finished product shall be smooth.

Any specimen shall be capable of withstanding the following test: The sample shall be cleaned before testing, first with carbona, benzine or turpentine and cotton waste (not with a brush), and then thoroughly rinsed in clean water and wiped dry with clean cotton waste. The sample shall then be immersed in a standard solution of copper sulphate for 1 min. and then removed, immediately washed in water and thoroughly wiped dry. This process shall be repeated. If, after

the fourth immersion there is a copper-colored deposit on the sample, or the zinc is removed, the lot from which the sample was taken shall be rejected. In the case of No. 14 galvanized-iron or steel wire, the time of the fourth immersion shall be reduced to ½ min.

69. Copper Sulphate Solution.—The standard solution of copper sulphate consists of commercial copper sulphate crystals in water. This solution has a specific gravity of 1.185 at 70 deg. fahr. While a sample is being tested the temperature of the standard solution should at no time be less than 60 deg. fahr., nor more than 70 deg. fahr.

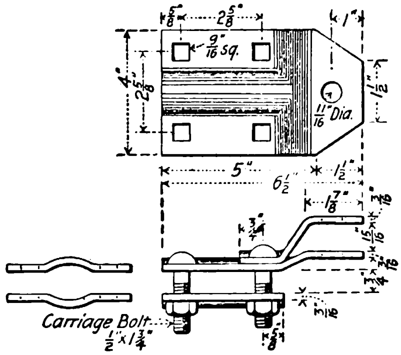


FIG. 61.—Dimensions of Matthew's cable clamp.

70. Cost per mile of pole-lines for 3-phase 2,300 to 6,600 volts. Data from six north-central and south-western states, 1909. From "Data," October, 1910. Figures are exclusive of painting, copper, engineering and general expense.

	Installation of minimum cost	Installation of maximum cost	Average
50 30-ft. poles	$171.00	$200.00	$218.90
50 sets pole hardware	8.30	16.00	10.25
50 2-pin cross-arms	17.00	11.50	14.00
150 insulators	6.75	11.20	9.00
Labor setting	55.00	200.00	109.00
Labor stringing wire	30.00	40.00	35.00
Incidentals	10.00	50.00	30.00
	$297.05	$528.70	$426.15

UNDERGROUND CONDUIT

71. Underground conduit construction is now an important and specialized branch of electrical engineering. In this book is given only enough information to enable one to lay out and install such minor underground structures as may be required in isolated plant or industrial plant work. Underground construction always costs more than overhead construction. In this country, "built-in" systems—those in which the cable is buried in the earth without protection—are seldom used because if trouble occurs on the conductors it is necessary to excavate to remove them.

72. Commercial duct materials are iron pipe, wood, cement-lined pipe, cement, vitrified clay and bituminized wood pulp. Only iron pipe, cement and virtified clay are recommended in this book as it is believed that, all things considered, these are the only materials that can be thoroughly depended on for power service.

73. **Creosoted wood ducts** are low in cost but will probably decay in time. Their life is said to be about twenty years if thoroughly creosoted. Wood ducts are inflammable and may burn in case of a short-circuit within them.

74. **Cement-lined pipe** was once used extensively but it was found that the arcs of short-circuits within such a duct cracked the cement lining. It chipped off and blocked the duct. There is little if any cement-lined pipe being installed at present.

74A. **Cement duct,** known as "Stone Duct," manufactured by a patented process that insures homogeneousness and strength is now being largely used in the Chicago district.

75. **Bituminized fiber duct** is easily laid and when new permits cables to be drawn into it readily because of its smooth oily interior surface. It is a comparatively recent product and its life is as yet undetermined. Furthermore, cases have been reported where duct lengths, in piles left to action of the heat of the sun, have been distorted by the weight of the duct lengths piled above them. Cases have also been reported where cables have stuck in fiber conduit and their withdrawal was thereby prevented. Probably this condition is most likely to occur where the duct is heated continuously either by overloaded conductors or by adjacent steam pipes. The upper portion of the duct sags down until it rests on the cable or possibly obstructs the duct if there is no cable in it.

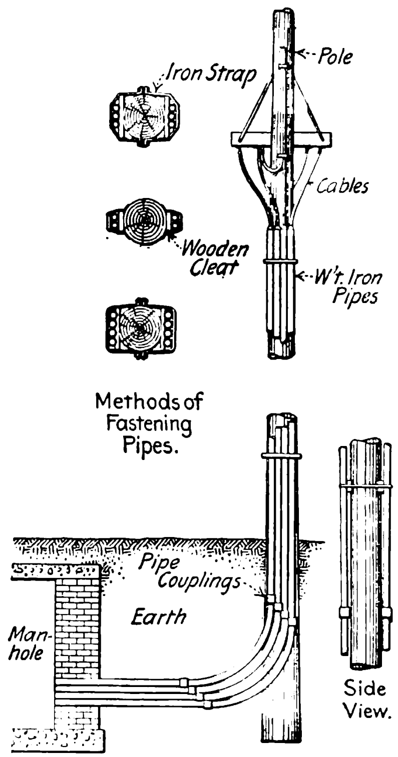


FIG. 61A.—Wrought-iron pipe laterals.

76. **Iron pipe** makes an admirable subway but its cost prevents its use except under certain conditions. Iron pipe appears to be the cheapest dependable duct material for laterals (Fig. 61, A) because it is not necessary to imbed it in concrete. It is also used where it is necessary to install many ducts in a limited space. It can be bent almost at will. Where it is necessary to thread a network of underground structures iron pipe is the only usable material. Where vitrified clay duct can be used it is to be preferred. Wrought-iron electrical conduit can be used for underground conduit but it is the practice of the larger companies to buy ordinary commercial wrought-iron pipe, usually 3 in. Wrought-iron pipe is preferable to steel pipe, which is often sold for wrought-iron, because the wrought-iron resists corrosion much more effect-

ively than does steel. See index for dimensions of wrought-iron conduit which are the same as those for wrought-iron pipe.

77. Vitrified clay single duct or hollow brick is the most popular for power cables. Fig. 62 shows a typical length. The dimensions of ducts furnished by the different manufacturers may vary from those of the illustration. The single duct is preferred because its walls are thick and in laying every joint is broken, eliminating the

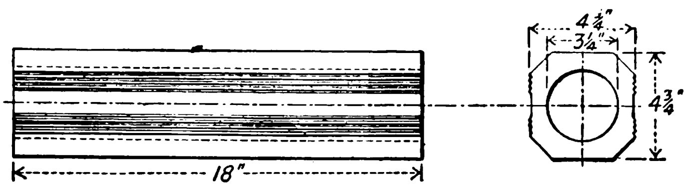


FIG. 62.—A piece of single duct.

possibility of the arc of a short-circuit on one cable affecting cables in other ducts in the same run. Single ducts can also be more readily laid around obstructions such as pipes and, furthermore, curves can be more readily formed with them than with multiple ducts.

78. Vitrified clay multiple duct is sometimes used for conduits for power cables but it is not as popular as single duct for the reasons given under "Single Duct." The four-way multiple duct is the

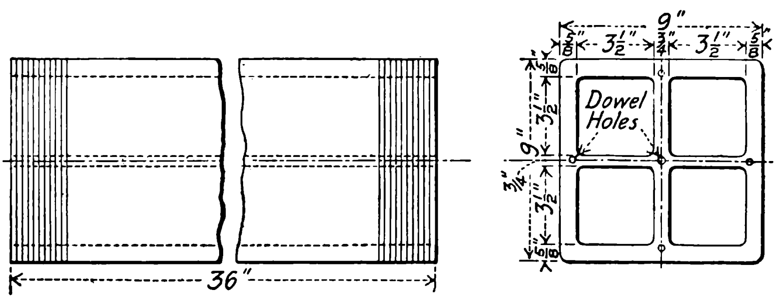


FIG. 63.—A piece of multiple duct.

most popular size (Fig. 63), although the six-way duct is frequently used. Nine,- twelve- and sixteen-way multiple ducts can be manufactured but they are seldom used because of their excessive weight and liability to breakage. The dimensions of the multiple ducts of a certain nominal size made by different manufacturers vary. Those shown in Fig. 63 for a four-way duct are typical.

79. In laying any kind of a conduit, after the trench is excavated its bottom should be rammed until solid and then leveled off and graded so as to pitch, from the center point between manholes toward each manhole, about 1 ft. in 100 ft. This is to insure effective drainage. The upper face of the conduit should be at least 2 ft. below the surface of the ground. The trench should

be 6 in. wider than the conduit to provide space for the 3-in. casing of concrete which is usually necessary around vitrified conduits. No wooden form is required for the concrete if the earth is compact and self-supporting. In yielding soils a rough wooden form, which can be removed after the concrete has set, can be used. The 3-in. bed of concrete should be placed parallel with the bottom of the graded trench. After the pieces of duct material are laid,

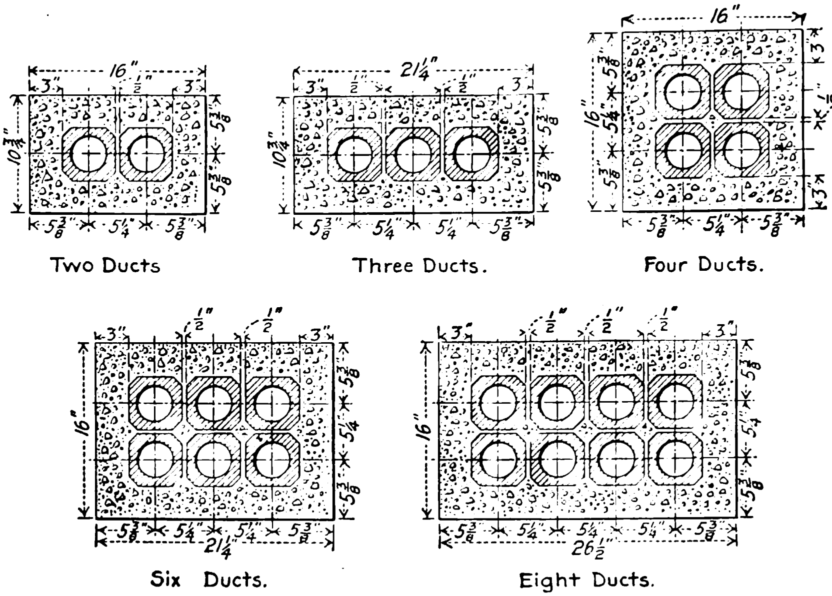


FIG. 64.—Arrangement of single-duct subway.

the 3-in. concrete sides should be carefully tamped in. Care must be taken not to disturb the duct alignment. Then the 3-in. concrete cover is spread over the ducts. Where the subway is composed of more than one tier, cement mortar should be placed between tiers as shown in the illustrations.

80. Laying Single-duct Conduit.—(See Fig. 64 for sections of single-duct runs.) A concrete bed, usually 3 in. thick, is placed on the bottom of the trench after the latter has been properly excavated, leveled and graded. After the bed is set the duct is laid in cement mortar. A mandrel (Figs. 65 and 66) is used to keep the successive pieces in line. It is customary to enclose the conduit in a continuous concrete encasement 3 in. to 4 in. thick.

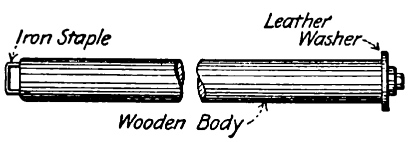


FIG. 65.—Mandrel for aligning conduit.

The mandrel is pulled through with a long hook as the conduit progresses, to align the ducts. The leather washer scrapes away any mortar that has oozed through between joints and leaves the duct quite clean. The end of a No. 12 galvanized-iron wire is frequently attached to the inner end of the mandrel and is pulled into

the conduit as its construction progresses. The wire is used to pull in the drawing-in rope which is used to pull in the cable.

The single ducts furnished by some manufacturers are provided with male and female ends which assist in aligning the ducts.

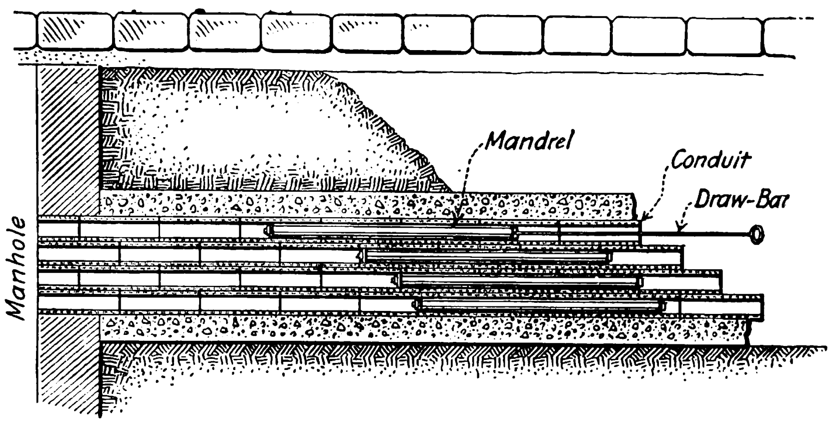


FIG. 66.—Showing use of mandrel.

81. Laying Multiple Duct.—Multiple duct is laid in about the same way as single duct. Fig. 67 shows sections of multiple-duct runs. The pieces are laid end-to-end and the joints, if there is more than one tier in the subway, are broken. The pieces are maintained in alignment by iron dowel pins or keys (Fig. 68)

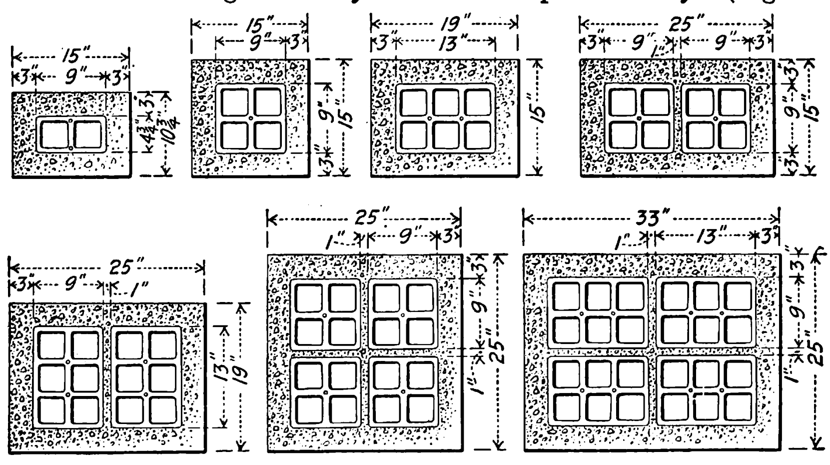


FIG. 67.—Sections of multiple duct.

which fit in holes in the pieces. All joints are wrapped with pieces of burlap or coarse muslin, 4 in. wide and 3 ft. long for 4-duct tile, which are moistened to make them stick. They are then coated with cement. The cloth prevents the entrance of cement or concrete into the ducts.

Sometimes a mandrel (Fig. 65) $\frac{1}{4}$ in. to $\frac{1}{2}$ in. smaller than the

hole is drawn through as the construction progresses, as suggested in Fig. 66, to insure alignment of the pieces. The handle on the mandril should be long enough to reach back two joints so that one may be sure that the last three pieces set align, as they may have become displaced in setting.

After the pieces are set, be careful that they are not displaced prior to depositing the concrete jacket. The ducts should be cleaned out after the concrete jacket has been placed by drawing a wire brush or flue cleaner (Fig. 69) through them. The brush is somewhat bigger than the duct hole. Sometimes a metal scraper (Fig. 69) is also used.

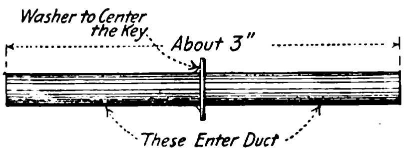


FIG. 68.—Steel key for multiple duct.

Multiple duct has been laid without any concrete casing, merely a concrete bed, as suggested in Fig. 70. This construction is economical in first cost but is apt to give trouble through settling of the earth or displacement due to future excavation. Creosoted boards are sometimes laid on top of a conduit run to protect against laborer's picks. Experience has shown that the average laborer will stop when his pick strikes a board but he will pick his way through concrete or duct material.

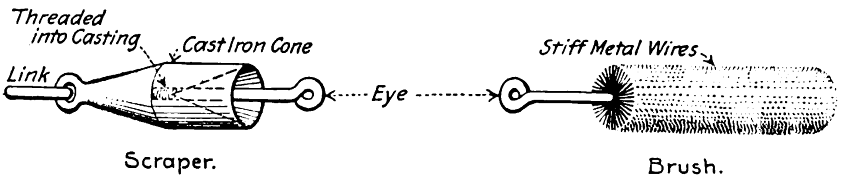


FIG. 69.—Scraper and brush for conduit.

Multiple-duct conduit can be carried around obstructions, as shown in Fig. 71, by beveling the ends of the pieces. If the turn is too short it may be difficult or impossible to "rod" the duct and to pull the cable in.

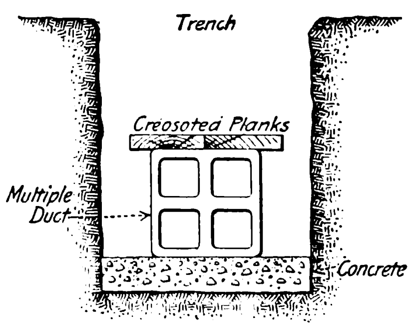


FIG. 70.—Protective planks over multiple duct.

82. To cut vitrified conduit a groove is chipped completely around the piece on the line at which it is desired to cut it. A hammer and cold-chisel are used for chipping the groove. Usually it will break off on the chipped line after continued chipping, but it may not. Some experience is required before one becomes skillful at this work. Short lengths can be furnished by the conduit manufacturers and their use is recommended.

83. In installing iron-pipe conduit no concrete casing is con-

sidered necessary if only one duct is involved. Where there are several ducts in the run, the ducts are sometimes laid on a 3-in. foundation of concrete and concrete is tamped between and around the ducts as shown in Fig. 64 for single vitrified duct. Where the ducts will not be exposed to the dangers of future excavation the cost of the concrete is probably not justified. Iron pipe is sold usually in 20-ft. lengths. Joints between adjacent lengths

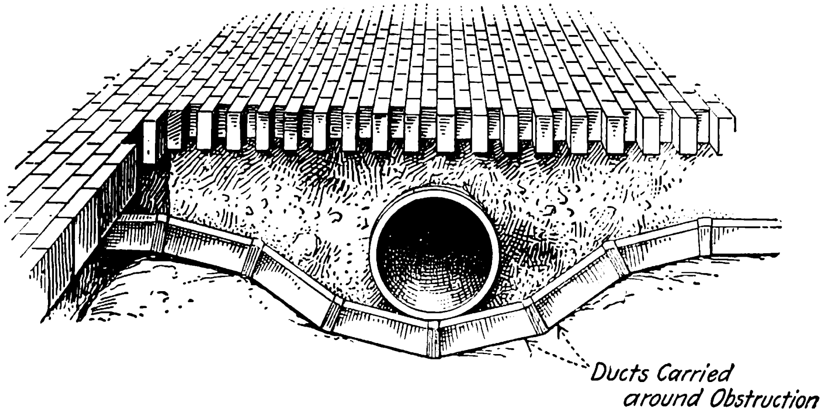


FIG. 71.—Breaking around an obstruction with vitrified duct.

are made with ordinary pipe couplings. (Fig. 61, *A*.) See Index for dimensions of conduit and fittings which are the same as those for pipe. The burrs at the ends of pipe lengths must be carefully removed to prevent damage to the cable. Where it is inconvenient to use a coupling, a pipe union can be used instead or the fitting can be omitted (Fig. 72) and the abutting ends encased in a block of concrete. The ends should be wrapped with a piece of sheet iron wired in position before the concrete is applied.

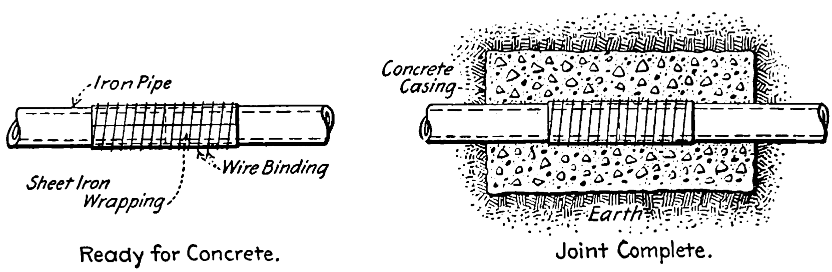


FIG. 72.—Cement joint on wrought-iron pipe.

Iron pipe for conduit is sometimes painted, inside and out, with asphaltum, but this is not considered necessary by all engineers.

84. Concrete for conduit work should be clean, that is, foreign substances should not be permitted to enter into its composition. If the surface on which it is to be mixed is not smooth and clean, mixing boards or pans should be used. Foreign material impairs the strength of concrete and it becomes porous and leaky. The

concrete should be mixed from Portland cement, clean sand, and gravel or broken stone, in the proportions by volume, of one part of cement to three parts of sand and five parts of gravel or stone. Just sufficient water should be used to thoroughly wet the mixture and to permit a small amount of water to come to the surface when the concrete is tamped into final position. The cement, sand and stone should be "turned" on the mixing board at least three times dry, and at least twice after wetting. The concrete should be placed immediately after mixing. When the concrete has been placed in the trench, several hours should be allowed for it to take its initial set before the trench is filled in. This is necessary to prevent throwing the ducts out of alignment, or fracturing the "green" concrete.

85. Cost of Laying Vitrified Conduit Per Lineal Foot (*H. C. Spellman, The World*, April 7, 1910).—Cost includes conduit, excavation, refilling, removal and replacement of pavement and a 3-in. jacket of concrete on all four sides of the conduit line. In fact, the figures shown are total costs for a complete subway run.

No. of conduits	Brick, granite, stone (grouted)	Asphalt tarred brick	Cedar (on concrete)	Cedar or cobble on sand	In grass plat	Dirt
1	$1.15	$1.10	$1.00	$0.70	$0.60	$0.50
2	1.25	1.20	1.10	0.80	0.70	0.60
3	1.35	1.30	1.20	0.90	0.80	0.70
4	1.45	1.40	1.30	1.00	0.90	0.80
5	1.55	1.50	1.40	1.10	1.00	0.90
6	1.65	1.60	1.50	1.20	1.10	1.00
7	1.75	1.70	1.60	1.30	1.20	1.10
8	1.85	1.80	1.70	1.40	1.30	1.20
9	1.95	1.90	1.80	1.50	1.40	1.30
10	2.05	2.00	1.90	1.60	1.50	1.40
11	2.15	2.10	2.00	1.70	1.60	1.50
12	2.25	2.20	2.10	1.80	1.70	1.60
13	2.35	2.30	2.20	1.90	1.80	1.70
14	2.45	2.40	2.30	2.00	1.90	1.80
15	2.55	2.50	2.40	2.10	2.00	.190
16	2.65	2.60	2.50	2.20	2.10	2.00
17	2.75	2.70	2.60	2.30	2.20	2.10
18	2.85	2.80	2.70	2.40	2.30	2.20
19	2.95	2.90	2.80	2.50	2.40	2.30
20	3.05	3.00	2.90	2.60	2.50	2.40
21	3.15	3.10	3.00	2.70	2.60	2.50
22	3.25	3.20	3.10	2.80	2.70	2.60
23	3.35	3.30	3.20	2.90	2.80	2.70
24	3.45	3.40	3.30	3.00	2.90	2.80

86. Manholes are necessary in a subway system to permit of the installation, removal, splicing and rearrangement of the cables. A manhole is merely a subterranean vault or masonry chamber of sufficient size to permit of proper manipulation of the cables. The conduits enter the vault and on its sides devices are arranged whereby the cables within the manhole can be supported.

87. The location of manholes is determined largely by the layout of the district that is to be supplied with power. Wherever a branch or lateral extends from the main subway there must be

a manhole, and there must be manholes at intersections of subways. In general, cables are not made in lengths exceeding from 400 ft. to 600 ft. and, as it is necessary to locate splices in manholes, the distance between manholes cannot exceed these values. Furthermore it is not advisable to pull in very long lengths of cable because the mechanical strain on the conductors and sheath may then become too great during the pulling-in process. It is recommended that manholes be located not more than 500 ft. apart.

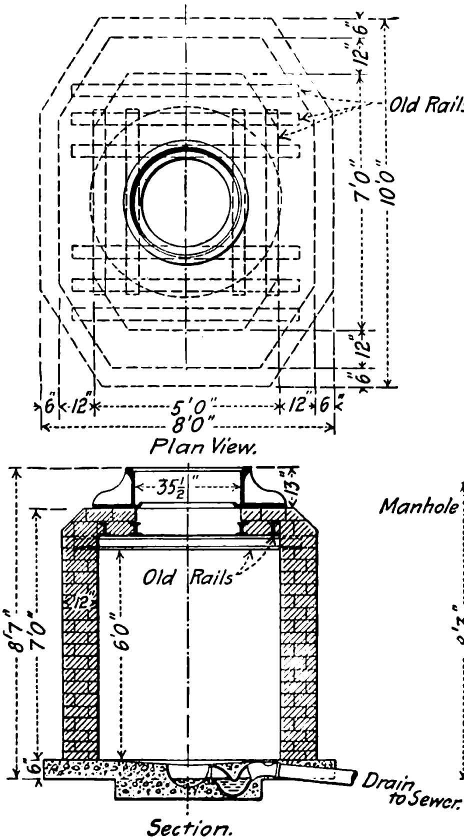


FIG. 73.—A 5 ft.×7 ft. brick manhole.

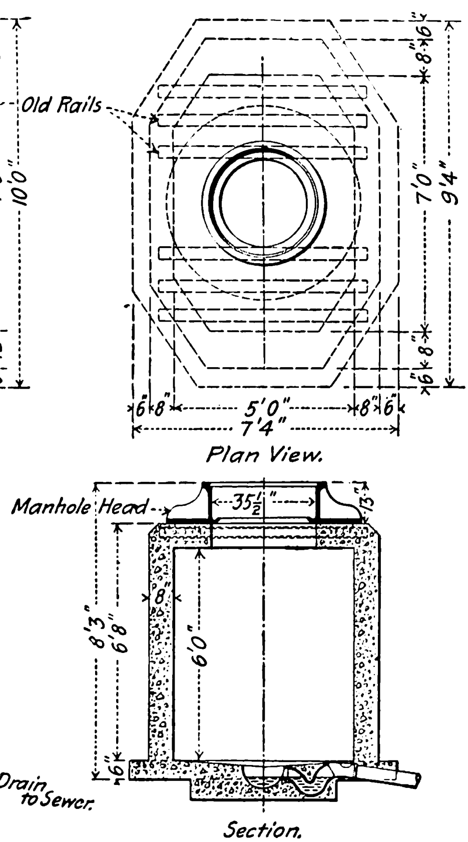


FIG. 74.—A 5 ft.×7 ft. concrete manhole.

88. Manholes are made of many shapes and sizes to meet the ideas of the designer and to satisfy local conditions. It is established, however, that the form shown in Fig 73 is best for the average condition. Where there are obstacles about the point where a manhole is to be located, the form of the manhole must be modified so as to avoid them. The form approximating an ellipse is used so the cables will not be abruptly bent in training them around the manhole.

89. Manholes are built of either brick or concrete, or of both of these materials. Where many manholes are to be built of one

size and there are no subterranean obstructions, concrete is usually the cheapest and best material. But where only a few are to be constructed or where there are many obstructions a manhole with a concrete bottom, brick sides, and a concrete top is probably the best. Such a manhole can be constructed without having to wait for concrete to set before forms can be removed and, furthermore, no forms, except some planks to support the top, are necessary

90. The size of manholes will vary with the number of cables to be accommodated, but in any case there must be sufficient

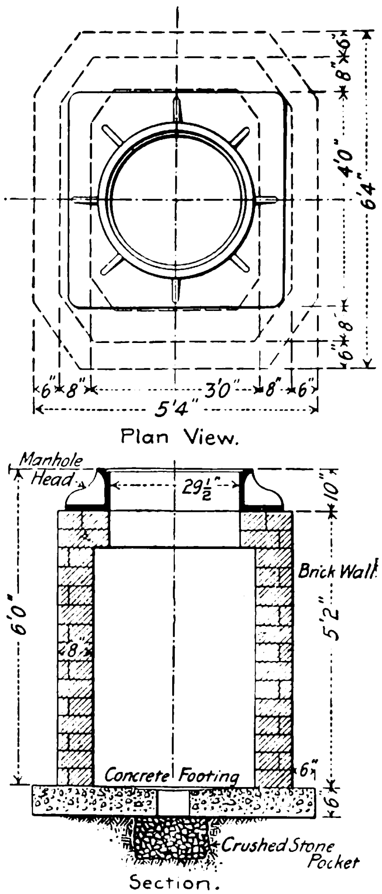


FIG. 75.—A 3 ft.×4 ft. manhole.

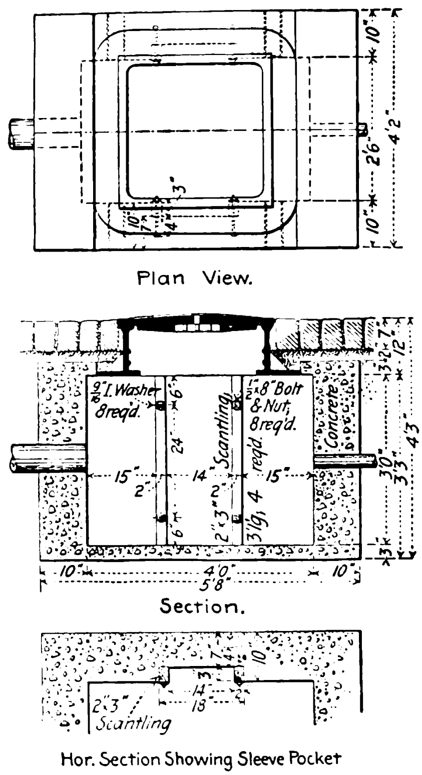


FIG. 76.—A concrete service box.

room to work in the manhole. A 5 ft. by 7 ft. manhole (Fig. 73) is probably as large as will be required in isolated plant work, while a 3 ft. by 4 ft. manhole (Fig. 75) is about as small as should be used.

91. A concrete manhole is built by first depositing the concrete floor (Fig. 74) and then erecting the form for the sides on this floor. In a self-supporting soil the sides of the hole constitute the form for the outside of the manhole. If the soil is not self-sup-

porting, an outer form of rough planks must be made which is usually left in the ground. Steel reinforcing—old rails are good—must be placed in the concrete top of a large manhole. In a small manhole the manhole head or cover will extend over the side walls and no reinforcing, or manhole roof for that matter, are required. All reinforcing steel should be completely encased in concrete to prevent corrosion.

92. **A manhole with brick walls is built** (Fig. 73) by first depositing the concrete floor and then building up the brick walls thereon. Where the manhole is large the roof can be of either

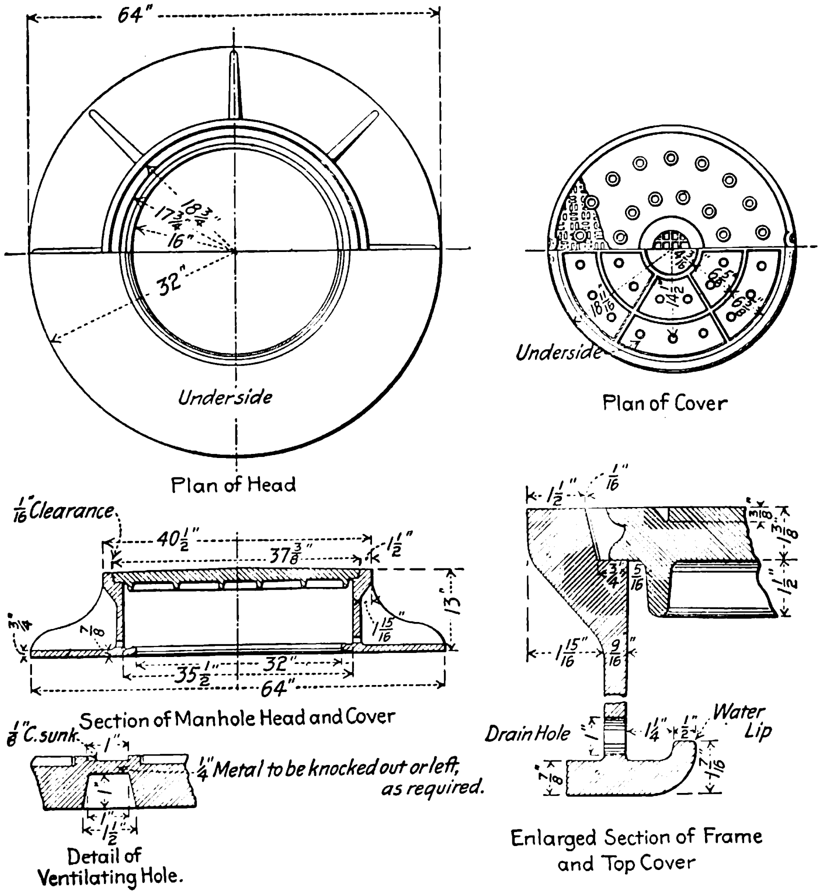


FIG. 77.—Head for large manholes.

steel-reinforced concrete or brick set between rails. Probably for installations where only a few manholes are to be built the brick-between-rails method is the best. For a small manhole no masonry roof is necessary as the cast-iron manhole head forms the roof.

93. **Distribution or service boxes,** so called, which are really small manholes, often serve the purpose of, and can be used instead of larger vaults in industrial and isolated plant installations. A

design for a concrete service box is shown in Fig. 76. A brick one would be of approximately the same dimensions. The depressions in the side walls are sleeve pockets. The splicing sleeves on the cables lie partially in these, after installation, and therefore less of the valuable working space of the box is occupied by them. In spite of the fact that a square manhole cover can fall into the hole, heads with square covers are often used for distribution boxes so as to provide an orifice giving maximum working room.

94. **Manhole heads** are frequently made of cast-iron, but cast steel is better. Fig. 77 shows a design for cast-iron, for a large

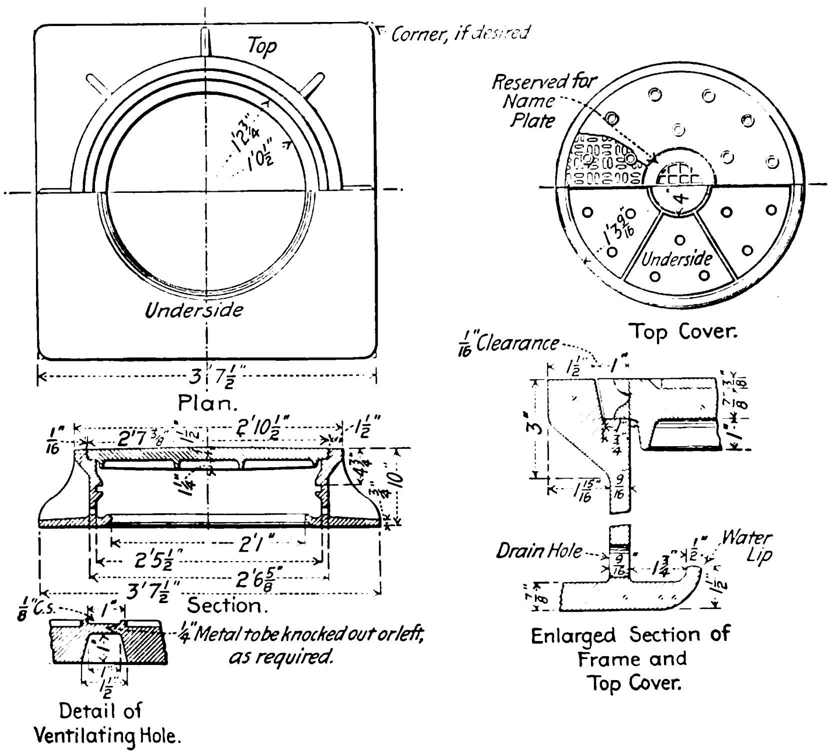


FIG. 78.—Head for small manholes.

manhole, and Fig. 78 one for a smaller manhole. Covers should be round so that they cannot drop into the hole. So-called water-tight covers are now seldom used as it is not feasible to make a satisfactory water-tight cover at reasonable expense and water gets into the manholes in any event. Covers should not be fastened down because if they are and accumulated gas in a manhole explodes, the vault will be shattered. If the manhole tends to fill with gas, holes should be made in the cover for ventilation. Dirt and water will get into the hole, but the dirt can be cleaned out and the water will drain out and no harm will result. If ventilation is not provided an explosion of gas may occur and do great damage.

95. Draining Manholes.—Where feasible, a sewer connection should lead from the bottom of every manhole. (See Fig. 74.) The mouth of the trap should be protected by a strainer, made of non-corrodable wire, such as that used for leader pipes. Where a sewer connection cannot be made there should be a hole in the manhole floor so that water can drain out. A pocket, filled with broken rock, under the hole will promote effective drainage. (See Fig. 75.)

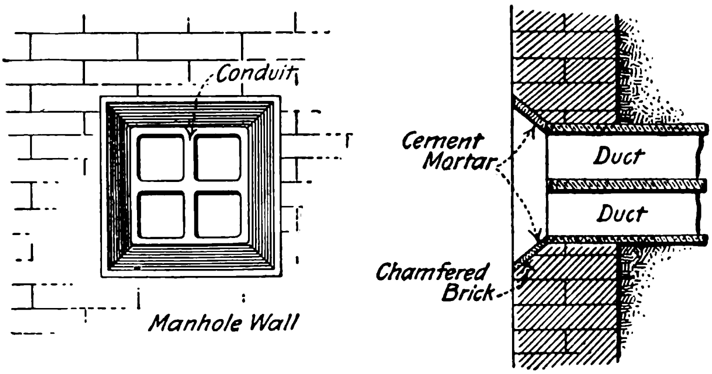


FIG. 79.—Chamfered wall at conduit entrance.

96. At the point where a conduit line enters a manhole the walls should be chamfered off as shown in Fig. 79 to prevent the damage that might occur if a cable is bent over a sharp corner.

97. A manhole hook, a convenient tool for removing manhole heads, is shown in Fig. 80. A common pick can be used, but the tool shown is much more convenient.

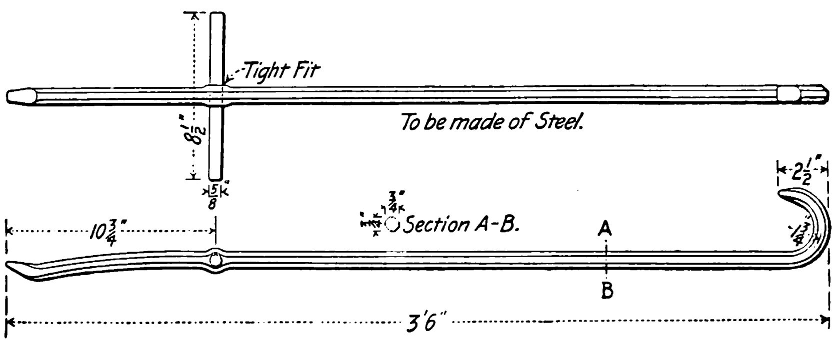


FIG. 80.—A manhole hook.

98. Cement mortar for building brick manholes or for conduit construction can be made by mixing together 1 part of cement and 3 parts of sand and about $\frac{1}{3}$ part of water, all by volume.

99. In installing cables in conduit, if a pull-in wire was not installed at the time the ducts were placed, the conduit is rodded, a pull-in wire or the drawing-in-cable is drawn through, cleaners are pulled through and then the cable is drawn in.

100. Average Cost of Manholes in Dollars

(Standard Handbook)

Brick with brick roof

Item	Amount	Rate ($) Min.	Rate ($) Ave.	Rate ($) Max.	Min. amt.	Per cent.	Ave. amt.	Per cent.	Max. amt.	Per cent.
Excavation	375 cu. ft.	0.02	0.03	0.04	$ 7.50	12.6	$11.25	11.8	$ 15.00	11.2
Concrete	0.7 cu. yd.	5.00	7.00	9.00	3.50	5.9	4.90	5.1	6.00	4.4
Brick	2,200	12.00	15.00	18.00	26.40	44.5	33.00	34.6	39.60	29.4
Cover	1	5.00	10.00	15.00	5.00	8.4	10.00	10.4	15.00	11.2
Iron	500 lb.	0.015	0.03	0.05	7.50	12.6	14.00	14.6	25.00	18.6
Repaving	6 cu. yd.	0.75	2.00	4.00	4.50	7.6	15.00	15.7	24.00	17.8
Cleaning	....	0.50	0.75	1.00	5.00	8.4	7.50	7.8	10.00	7.4
Totals	....	....	....	....	$59.40	100.0	$95.65	100.0	$134.60	100.0

Brick with concrete roof

Item	Amount	Rate ($) Min.	Rate ($) Ave.	Rate ($) Max.	Min. amt.	Per cent.	Ave. amt.	Per cent.	Max. amt.	Per cent.
Excavation	375 cu. ft.	0.02	0.03	0.04	$ 7.50	14.8	$11.25	14.4	$15.00	13.8
Concrete	1.9 cu. yd.	5.00	7.00	9.00	9.50	18.7	13.30	17.0	17.10	15.7
Brick	1,600	12.00	15.00	18.00	19.20	37.8	24.00	30.7	28.80	25.7
Cover	1	5.00	10.00	15.00	5.00	9.9	10.00	12.8	15.00	13.8
Repaving	6 cu. yd.	0.75	2.00	4.00	4.50	8.9	12.00	15.4	24.00	21.9
Cleaning	....	0.50	0.75	1.00	5.00	9.9	7.50	9.5	10.00	9.1
Totals	....	....	....	....	$50.70	100.0	$78.05	100.0	$109.90	100.0

Concrete manhole

Item	Amount	Rate ($) Min.	Rate ($) Ave.	Rate ($) Max.	Min. amt.	Per cent.	Ave. amt.	Per cent.	Max. amt.	Per cent.
Excavation	375 cu. ft.	0.02	0.03	0.04	$ 7.50	16.8	$11.25	15.5	$ 15.00	14.3
Concrete	4.5 cu. yd.	5.00	7.00	9.00	22.50	50.5	31.50	43.6	40.50	38.8
Cover	1	5.00	10.00	15.00	5.00	11.2	10.00	13.9	15.00	14.4
Repaving	6 cu. yd.	0.75	2.00	4.00	4.50	10.2	12.00	16.6	24.00	23.0
Cleaning	....	0.50	0.75	1.00	5.00	11.3	7.50	10.4	10.00	9.5
Totals	....	....	....	....	$4.50	100.0	$72.25	100.0	$104.50	100.0

101. Cost of Sewer Connection in Dollars

Item	Amount	Rate ($) Min.	Rate ($) Ave.	Rate ($) Max.	Min. amt.	Per cent.	Ave. amt.	Per cent.	Max. amt.	Per cent.
Excavation	225 cu. ft.	0.02	0.03	0.04	$ 4.50	35.1	$ 6.75	26.0	$ 9.00	21.4
Concrete	5 cu. yd.	0.75	2.00	4.00	3.75	29.2	10.00	38.8	20.00	47.0
Cover	1	1.00	2.50	4.00	1.00	7.6	2.50	9.6	4.00	9.3
Repaving	16 ft.	0.04	0.07	0.10	0.64	5.0	1.12	4.4	1.60	3.6
Brick	....	0.50	0.75	1.00	1.00	7.6	1.50	5.8	2.00	.47
Cleaning	1	2.00	4.00	6.00	2.00	15.5	4.00	15.4	6.00	14.0
Totals	....	....	....	....	$12.89	100.0	$25.87	100.0	$42.60	100.0

102. **Rodding.**—Rods are pieces of round hickory about $\frac{3}{4}$ in. in diameter and 3 ft. long. (See Fig. 81.) The ends of the rods are equipped with brass knuckle-joint fittings so the rods can be readily joined together and disjoined. In rodding, a rod is pushed into the duct and a second rod is coupled to it. The two are pushed into the duct and a third rod joined on and the process is repeated until the rods extend from manhole to manhole. A galvanized-iron wire is attached to the last rod and the wire is drawn into the duct.

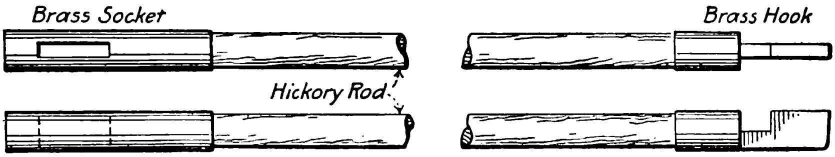


FIG. 81.—Rods for conduit.

A rope or flexible steel cable to which are attached a scraper and a brush (Fig. 69) is drawn through to insure that the duct is clear and clean. To the end of this rope or cable another is attached which is used to pull in the electrical conductor cable.

Where the conduit is short, a steel fish wire or ribbon, like that used by electricians in wrought-iron conduit work, can be inserted instead of the rods. Sometimes a "fish" made of lengths of flexible bamboo is used instead for laterals and other short runs.

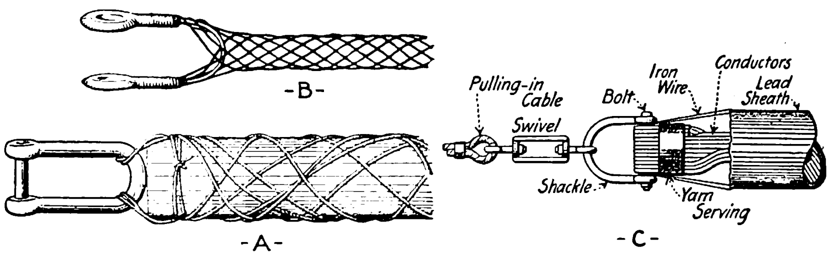


FIG. 82.—Methods of attaching cable to drawing-in line.

103. **Pulling in Cable.**—The cable can be attached to the pulling-in wire by any one of several methods. Fig. 82, *C* shows one that was formerly much used. Probably the best methods are those illustrated in Fig. 82, *A* and *B*. At *A*, a galvanized iron wire is laced around the cable in such a way that the harder it is pulled the tighter it grips. At *B* is shown a "grip" spirally laced from flexible steel strands. It slips over the cable sheath readily, but when tension is applied it effectively grips the cable. A swivel should always be inserted in any pulling-in line to prevent the untwisting of the drawing-in line under tension from twisting the cable.

After the cable is fastened to the pulling-in line a "protector" is placed in the mouth of the duct to prevent abrasion of the cable. Metal protectors can be purchased, but a good one can be formed from a piece of sole leather.

The cable is bent, as shown in Fig. 83, from the cable reel to the mouth of the duct and the pulling in commences. In the far manhole sheaves are arranged over which the pulling-in line passes. (See Fig. 83.) If eye bolts were built in the manhole sides the sheaves (snatch-blocks) can be fastened to them. Otherwise a guide-sheeve-rack (see Fig. 84 for detail and Fig. 83 for application) can be set up in the manhole.

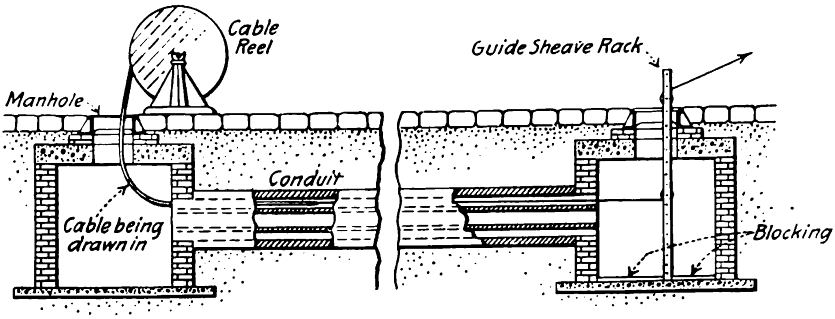


FIG. 83.—Drawing in cable with winch.

A winch or horses can be used for the pulling. Men can pull a cable in if the run is not too long. The cable sheath should be greased as it is drawn in to insure easy pulling. Where a length of cable longer than the distance between manholes is to be pulled through, it can pass over the sleeves on the guide sleeve rack, provided they are large enough in diameter. A cable should not be bent to any radius smaller than 10 times its diameter. A manhole capstan, Fig. 85, is sometimes used instead of a winch on the surface of the ground. Enough cable should be pulled into the manhole to allow for forming it around the hole and splicing it. Do not permit a cable to hang over the sharp edge of a duct. Support it in the rack.

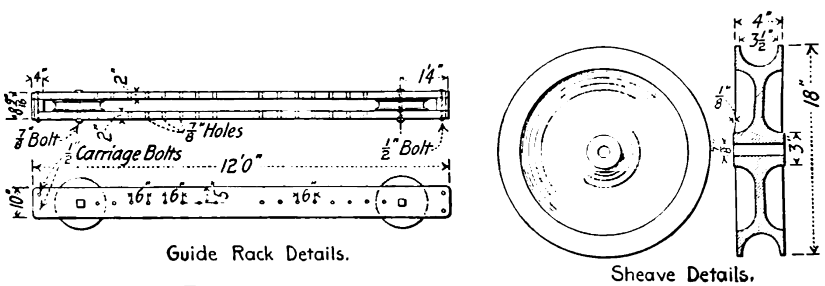


FIG. 84.—Guide sheave, rack and sleeve.

104. Supporting Cables in Manholes.—Some provision must be made. Creosoted planks, Fig. 86, are sometimes bolted to the manhole sides and the cables are held to the cleats with pipe straps. In other cases metal supports are used several forms of which are on the market. One that can be readily made is shown in Fig. 87. Shelves around the sides of the manholes can be formed of bricks as shown in Fig. 88. This is an excellent and probably the best method.

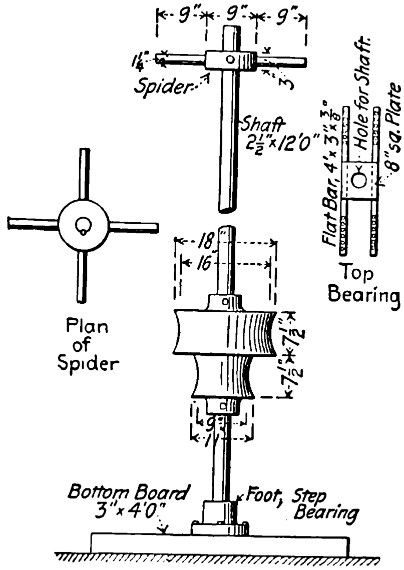


FIG. 85.—Manhole capstan.

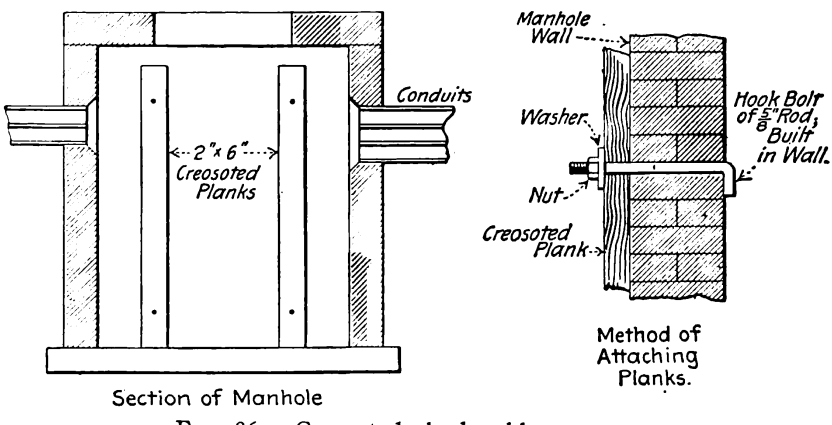


FIG. 86.—Creosoted plank cable supports.

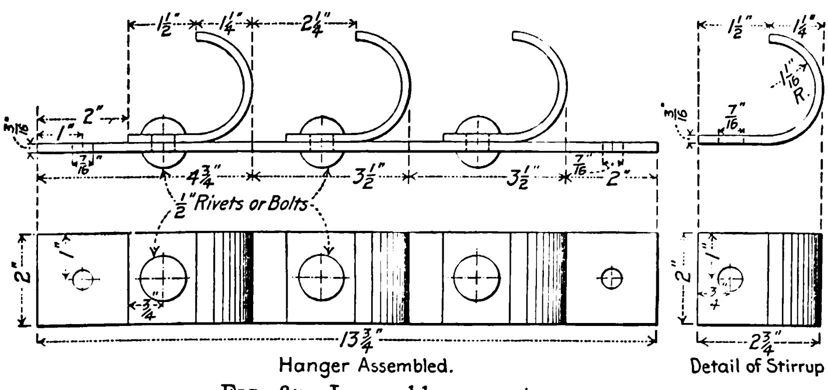


FIG. 87—Iron cable support.

105. Eyebolts or stirrups should be set in manhole walls to provide means of attachment for the tackle used in pulling in cable. (Fig. 88.) An eyebolt or stirrups should be set opposite the point of entrance of each subway. Fig. 89 shows the dimensions of a suitable stirrup.

106. Several Cables Should not be Placed in One Duct.—Experience has shown that while it is easy enough to install cables

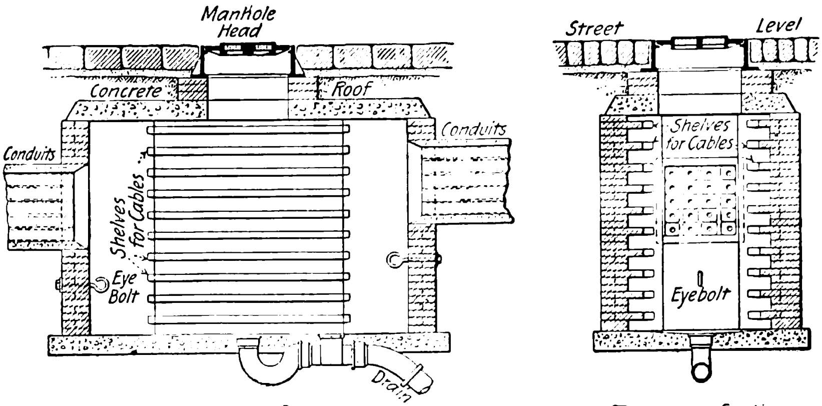


FIG. 88.—Cable shelves of brick.

under such conditions and mechanically easy to withdraw them, the removal almost invariably ruins the cable, because after long lying in a duct the cables become so impacted with dust and grit that when one is drawn out the sheath is either stripped from the cable itself, or from one of its companions. Consequently conduits are now almost exclusively built by arranging a sufficient number of ducts so that each cable may have its own exclusive compartment.

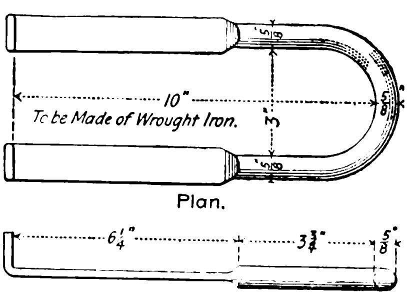


FIG. 89.—Stirrup for manhole wall.

107. In manholes and ducts cables should be so arranged that there will be a minimum of crossing and recrossing. An underground cable system should be carefully planned and the ducts should be so chosen for the cables that, insofar as feasible, a cable will take the duct in the same relative position throughout the subway.

DESIGN OF DISTRIBUTION INSTALLATIONS

108. In designing an installation of conductors for the distribution of electricity there is no royal road. It is rather a "cut-and-try" process and frequently, for a reasonably large installation, many tentative lay-outs must be made before the most suitable one is found. The design of such lay-outs is affected by so many conditions that only the most general suggestions can be given. Review the information on distribution in the "Fundamentals" section of this book.

109. In laying out any electrical distribution system the first step, if the system is of any consequence, is to note on a scale map of the territory to be served, the locations at which electricity will be required and the amount of power that will be taken at each. In general, each building in the area to be served is considered as a unit as it is seldom advisable to install more than one

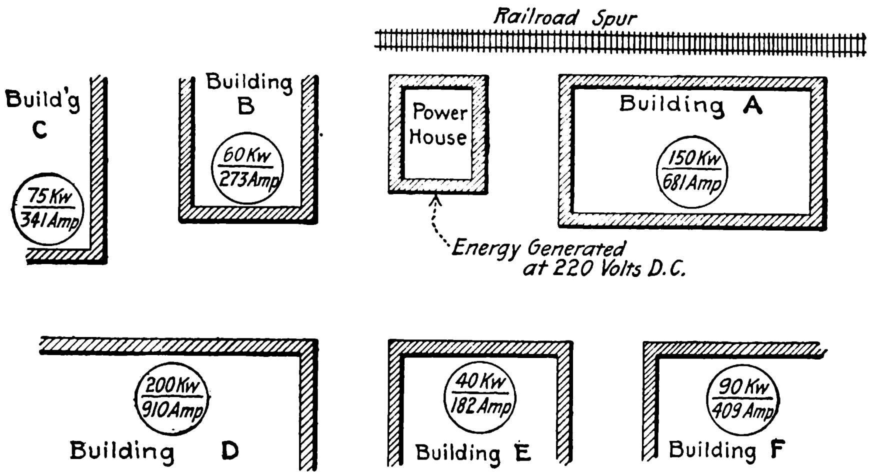


FIG. 90.—Power and current demands in an industrial plant.

service to a building. Fig. 90 shows such a lay-out for an imaginary industrial plant and Fig. 91 for a portion of a town. The values within the circles indicate the maximum power demands. That above the horizontal line is the power demand in kilowatts and the value below the line is the current, the power factor being considered if the system is to be alternating current. If separate circuits are to be maintained for light and for power, which is usual practice, the power demand for each circuit should be noted. In the illustrations (Figs. 90 and 91) it is assumed, for simplicity, that power and lighting devices are served from the same circuits. The current is noted in addition to the power demand because it is necessary to know the current to determine the capacities of fuses and switches and to check conductor sizes for current-carrying capacity.

110. Lay-out of Feeders and Mains.—After the locations of the points where energy will be required have been plotted and the amount of power that will be required at each has been noted,

the feeders and mains can be laid out and the conductor sizes for them calculated. No hard and fast directions can be given. Each case must be treated individually in accordance with the conditions to be satisfied. The desideratum is to so plan the lay-out that the cost of the conductors and their supports will be a minimum and that, at the same time, the energy loss in the conductors will be reasonably small, and the whole system will be as reliable in operation and the voltage regulation will be as close as conditions warrant. Sometimes considerable expense is justified to secure reliability and close voltage regulation, but in other cases reliability and close voltage regulation are unimportant and the cheapest lay-out that will give service is the most desirable. Whether the distribution conductors are to be carried overhead—on poles or buildings—or underground will affect their routing.

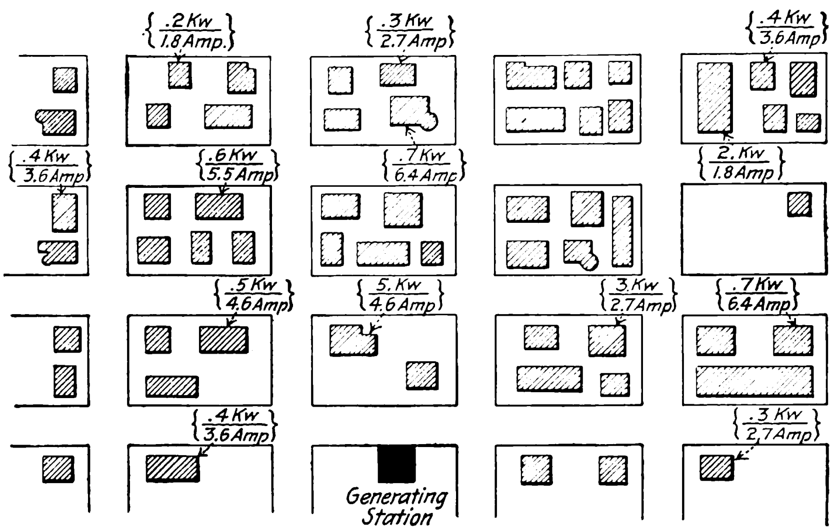


FIG. 91.—Power and current demands in a small town.

111. **The magnitude of load that should be served by one feeder or main** is altogether a relative matter and depends to an extent upon the flexibility of control and of metering desired and on the station capacity. In industrial plant installations if it is desired to meter in the generating station the energy supplied to different departments or buildings, obviously an individual circuit must be carried from the switchboard to every such building. It should be possible to disconnect portions of the load at the powerhouse, in case of trouble with the generators or in case a heavy load increase is thrown suddenly on the station, to tide over an emergency without shutting down the entire plant. In general, in a small station, the load on any feeder should not be larger than can be readily carried by any one of the generating units and it is better to have the load further subdivided. Usually a load divides itself naturally into convenient units because of the arrangement of buildings, groups of buildings, departments or other topographical or commercial considerations.

112. **Mains are Sometimes Tapered.**—A tapered main is one in which the conductor size diminishes from the point of source of energy outward. (See Fig. 92.) It is usual, and ordinarily the best, practice to use a main of the same size conductor throughout its length. Splices and intermediate cut-outs are thereby avoided. Theoretically, a tapering main, assuming a given maximum drop, does not effect a saving in copper as is often but erroneously believed. See Crockers, *Electric Lighting*, Vol. I, page 32.

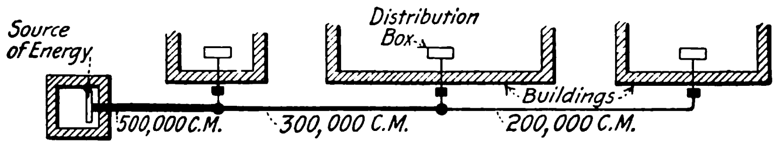


FIG. 92.—A tapered main.

113. **The calculation of wire sizes for feeders and mains** for distribution installations are made similarly to those for interior circuits. Methods and examples of calculation for the different systems are given in the **"Fundamentals"** section of this book.

114. **Overhead vs. Underground Distribution.**—Whether an overhead or underground distribution should be used depends in the case of small or medium-sized installations very largely on how much can be spent for appearances. An overhead system, properly installed, can be made thoroughly reliable and will usually cost much less than an equivalent underground system. Sometimes in

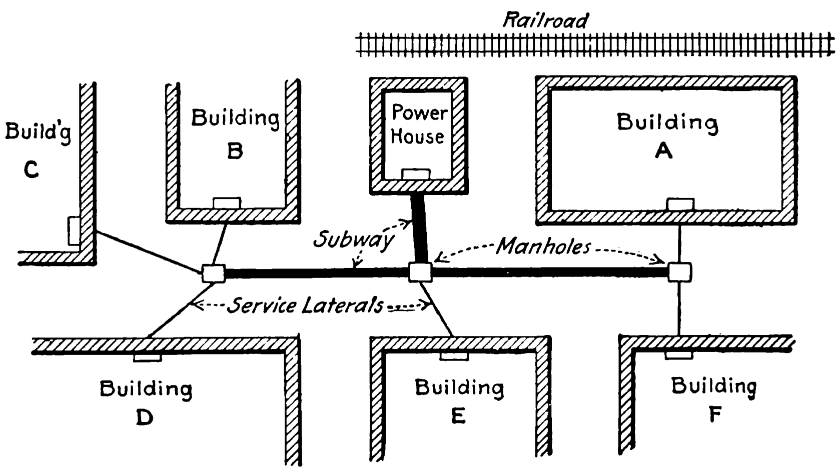


FIG. 92A.—Conduit system for underground distribution.

industrial plant work it is necessary to build subways for pipes in any event and when such subways can also be utilized for electrical conductors a low installation cost may be possible.

115. **If the distribution conductors are to be carried underground** in conduit it is necessary to group the runs insofar as possible, as suggested in Fig. 92, *A*, to insure minimum cost for excavation and manholes.

116. **If the distribution conductors are to be carried overhead,** more direct routes can be selected, as with overhead distribution conductors can, in industrial plant work, be carried over buildings in the most direct routes.

118. **A combination main feeder or other circuit** is one that serves all energy consuming devices, motors, lights and minor miscellaneous equipment.

119. **An independent main, feeder or other circuit** is one that serves only motors and similar equipment or only lighting devices.

120. **Independent vs. Combination Circuits for Lights and for Motors.**—One of the first things to be decided is whether individual circuits from the switchboard out will be used for lighting and for motors. It is desirable to use independent circuits because it is then possible, at reasonable expense, to maintain a much closer voltage regulation, hence steadier illumination on the lighting circuits. Furthermore, since troubles such as heavy short circuits and grounds occur more often on motor circuits than on lighting circuits, the possibility of such troubles throwing a building or an area in darkness is a minimum with independent motor and lighting circuits.

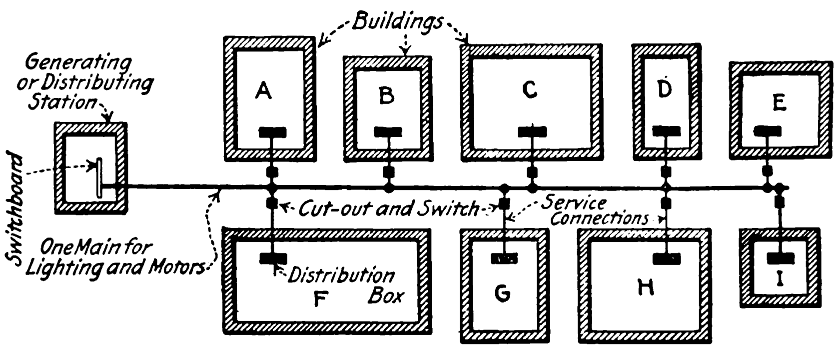


FIG. 93.—Combination main for lighting and motors.

121. **Main and feeder lay-outs for industrial plants** are shown diagrammatically in Figs. 93 to 99. While these apply principally to industrial plant installations, the principles involved are the same as for municipality electricity distribution. However, because of the different conditions, municipality distributions are handled somewhat differently. In these diagrams, which illustrate principles rather than actual installations, *A*, *B*, *C*, *D*, etc., represent the buildings in an industrial plant. A single line represents an entire circuit, two wires for a direct-current, two-wire circuit; three wires for a three-wire circuit, etc. The diagrams apply to any system of distribution. The service wires from the distribution circuits enter the buildings and terminate in distribution boxes—panel boxes or groups of cut-outs. From the distribution boxes the interior motor and lighting circuits, which are not shown, are supposed to radiate. For information regarding the lay-out of interior wiring circuits, refer to the section on *Interior Wiring*. See Index.

122. **A combination main for lighting and motors** (Fig. 93) can be used where the installation must be of minimum expense. In the illustration a single main, which may be either carried underground on poles or on fixtures attached to the buildings, extends from the switchboard. Service connections are tapped from the main for each building or group of buildings and are terminated in a distribution box—a panel box or a group of porcelain cut-out fittings—within the buildings. Since the service conductors will

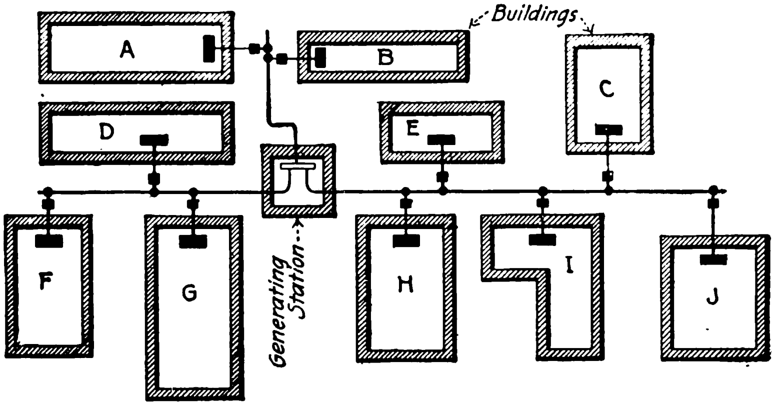


FIG. 94.—Combination mains serving groups.

be smaller than the main conductors a cut-out and, preferably, a switch are inserted in each. The only thing to commend a lay-out like that of Fig. 93 is its low first cost. With such a lay-out the voltage regulation on the lighting circuits is apt to be bad and a ground or short-circuit on any circuit may put the entire plant out of commission. With this arrangement the station operator has no control over the use of the power and if he wishes to decrease the load on the generators by cutting off certain portions of the plant he has no means of doing so. It is an example of "all of the eggs in one basket."

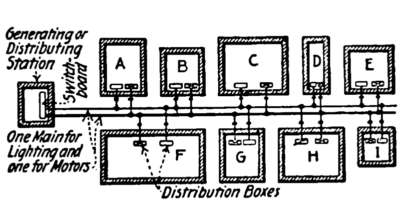


FIG. 95.—Independent main for lighting and one for motors.

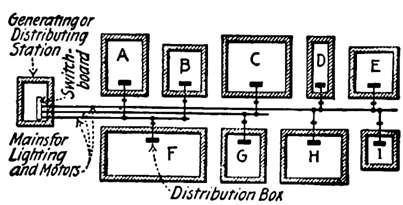


FIG. 96.—Combination mains serving groups.

123. **Independent mains for lighting and motors** (Fig. 95) are sometimes used. This is a better arrangement than that of Fig. 93 in that the lighting circuits are entirely separate from the motor circuits. But, if many lights or many motors are served by one main, trouble is apt to occur. Furthermore, it is not possible to control the power supply of each building from the generating or distributing station.

124. Combination Mains Serving Groups (Fig. 96).—This is a modification of a single combination main lay-out and is sometimes used and is permissible in certain instances where the installation cost must be low. It is better than a single combination main arrangement, but is not very good as no arrangement is good where lights and motors are fed from the same circuit, unless the motor load is relatively unimportant. The station operator has some control over his load and the load is sufficiently sectionalized so that all "eggs are not in one basket." Fig. 94 shows another example of combination mains serving groups.

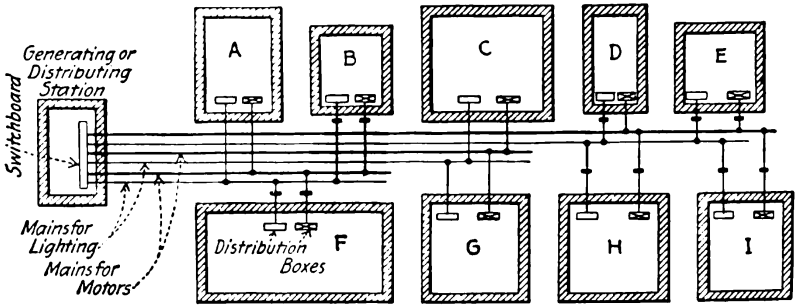


FIG. 97.—Independent mains serving groups.

125. Independent Mains Serving Groups (Fig. 97).—This is a fairly good arrangement if the groups are not too large. Its possible disadvantages are that with it it is not feasible to meter the energy to each unit in the group at the generating station nor is it possible to disconnect each unit from the generating station. These are not always disadvantages. Such an arrangement judiciously laid out will give excellent service.

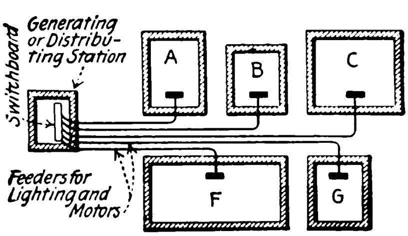


FIG. 98.—Combination feeders for lighting and motors.

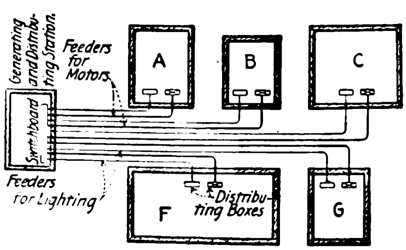


FIG. 99.—Independent feeders for lighting and independent feeders for motors.

126. Combination feeders (Fig. 98) possess the advantages that the load is well divided—"few eggs in a basket"—and that each feeder circuit can be readily controlled and metered at the generating station. But they possess the disadvantages, already enumerated, that always obtain where lighting appliances and motors are served by the same circuit. As a general proposition, such a lay-out is not to be recommended, though it may give satisfactory service where the conditions are not exacting.

127. Individual feeders (Fig. 99) provide the ideal lay-out

for reasons that have been suggested in preceding paragraphs. It is seldom that it is advisable to run a feeder to every building in a group. A combination of the methods of Figs. 97 and 99 is usually used. Individual feeders are carried to the principal buildings and mains are arranged on the group plan to serve the buildings having small loads.

128. **A direct-current, two-wire distribution** is seldom used for any installation except a small industrial plant. The voltage may be either 110 or 220. If most of the load is lighting 110 volts may be used. But, if the load is of any consequence, the conductors will be very large for 110 volts hence 220 is more often used. The feeders and mains in an industrial plant can be laid out in accordance with any of the methods of Figs. 93 to 99 but, as outlined in connection with those illustrations, the methods of Figs. 97 or 99 are to be preferred. See the First Section for information in regard to the disadvantages of operating incandescent lamps at any other voltage than 110. If a direct-current two-wire system is used for a municipality the feeders and mains can be laid out somewhat as suggested in Fig. 100.

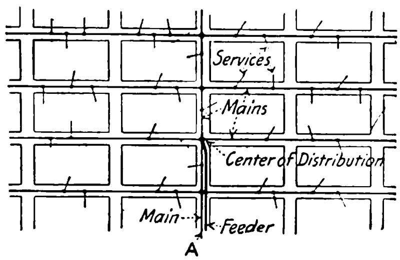


FIG. 100.—Primary distribution in a municipality.

129. **Direct-current, three-wire distributions** are frequently used in industrial plants where there are many adjustable-speed motors for machine tool drive and the like. Direct-current, three-wire distributions are also sometimes used in small municipalities.

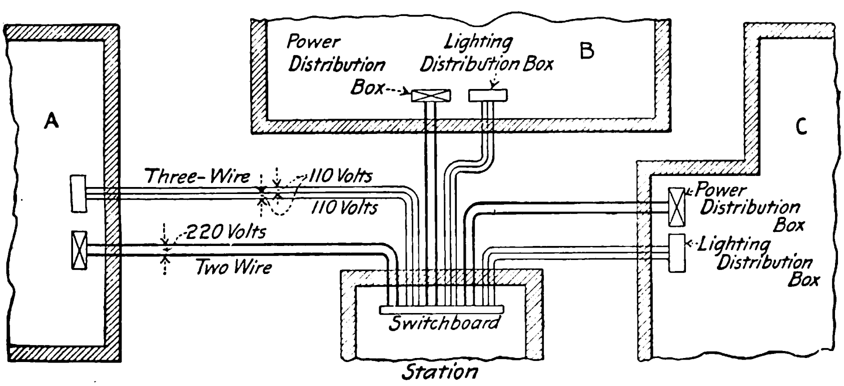


FIG. 101.—Three-wire distribution.

In either case the voltages are almost invariably 110 and 220. The best method for an industrial plant is suggested in Fig. 101 wherein separate feeders are carried from the switchboard to each building or group of buildings for lighting and for power service. The lighting feeders are three-wire so that the incandescent lamps can be operated at 110 volts. The motor feeders are usually 220 volts, two-wire unless some scheme of motor speed control is used that

requires all three wires. In municipalities, since the load is usually mainly lighting, all feeders and mains are three-wire and are laid out as suggested in Fig. 100. This represents the arrangement in a small town or that in one of several similar districts of a large one.

130. Single-phase, alternating-current, high-voltage distributions are seldom used in industrial plants, but are often used in municipalities. The voltage is usually 2,200; 1,100 was at one

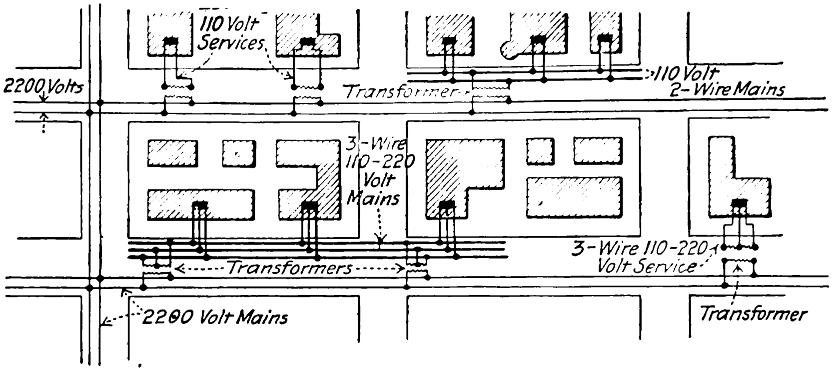


FIG. 102.—Single-phase, high-voltage distribution.

time popular, but was found to be too low for economy. In a municipality, a feeder can be installed to serve each district (Fig. 100) and an automatic potential regulator can, if necessary, be cut into the feeder and so arranged to maintain the voltage constant at the center of distribution. If no regulator is used the feeder might connect into the nearest point as *A* (Fig. 100) of the distribution system. Consumers are served through transformers which

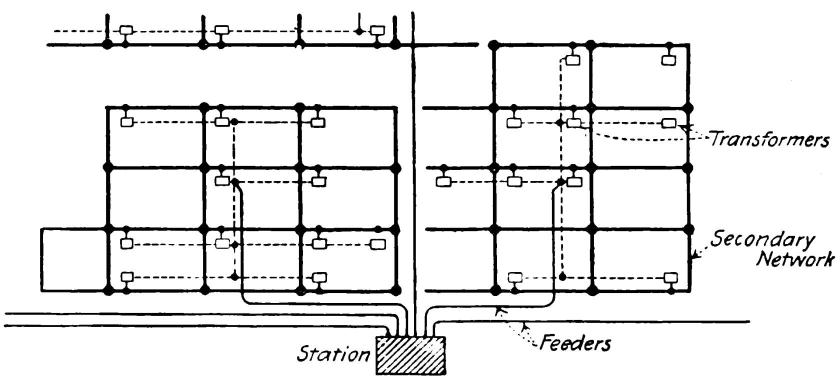


FIG. 103.—An alternating-current secondary network.

reduce the voltage (see Fig. 102) from 2,200 to 110 or 110–220 three-wire. (See section on *Transformers*.) Small single-phase motors, of capacities smaller than say 5 h.p. can be supplied from the secondary conductors, but a separate service should be run for motors of capacities greater than 1 h.p. If motors larger than 5 h.p. are used it is well to serve them with a separate feeder.

Fig. 102 shows methods of serving subscribers. Single transformers are used for detached subscribers. Where several subscribers are grouped it is good practice to run a secondary main supplied by one or more transformers. Through this arrangement the use of small transformers is avoided and the investment in transformers is decreased. Large transformers are more efficient than small ones.

Secondary mains are usually made three-wire (Fig. 102) and the advantages of the three-wire system (see *First Section*, Index) are thereby realized. Where the load is dense the secondary mains are tied together into a network (Fig. 103). Closer regulation is thereby assured. Such a network is usually 110–220 volts, three-wire. In modern practice, single-phase generators are seldom built. Alternating-current generators are usually three-phase, but feeders may be single-phase and they are tapped from three-phase bus-bars as suggested in Fig. 104. The single-phase loads should be, approximately, balanced on the three phases.

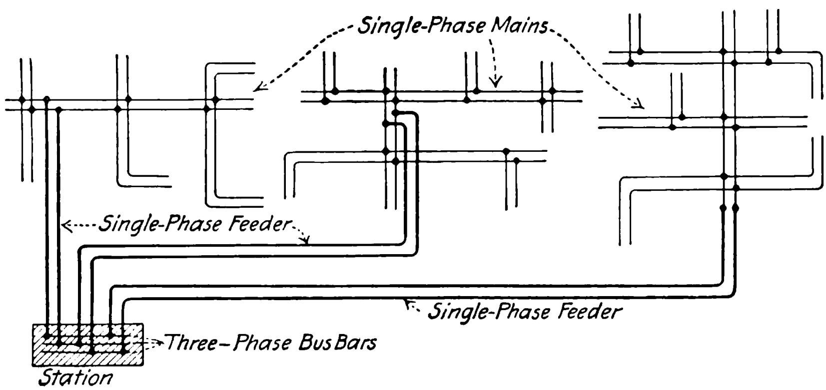


FIG. 104.—Single-phase distribution in a municipality.

131. Single-phase Distribution in Denver, Colo. (*Elec. World*, Dec. 2, 1911).—See Fig. 105. The lighting service is fed by multiple, single-phase, 2,200-volt primary feeders and mains, supplying energy to secondary networks throughout the urban districts through step-down transformers located at important centers of distribution and feeding individual consumers at 110 volts and 220 volts, according to the local load requirements.

The single-phase alternating-current system consists of twenty-six two-wire, 2,200-volt feeders extending from the station bus-bars to the electrical center of a definite section of the city which is electrically independent of any other section or feeder. The primary mains extend from the center of distribution in each section in the form of laterals or branches supplying energy to the most remote transformers of the district with the usual inclusion of intermediate transformers bunched, so far as practicable, to secure economy of operation and reasonable first cost. Any feeder may be fed from a special auxiliary bus in the station in case repairs, adjustments or inspection are necessary in connection with the switches and regulators in routine service.

Within a given section, the secondaries of all transformers are connected by three-wire tie lines forming low-tension bus-bars from which the leads to the various consumers are tapped. The transformers used on the lighting system vary in size from ½ kw. to 50 kw., and all above 1-kw. rating are connected for 2,200 volts

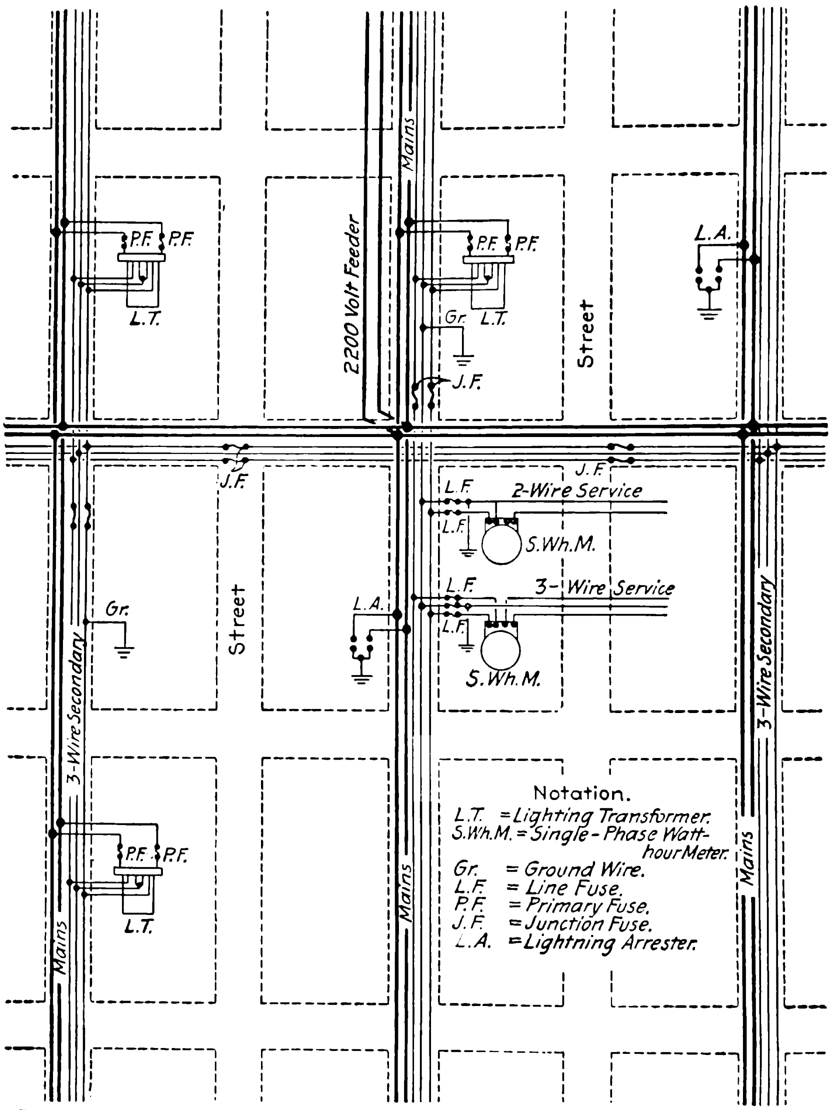


FIG. 105.—Single-phase feeder with high- and low-tension distributions.

on the primary. Each of the two secondary coils is connected so as to give 110 volts between the middle or neutral line and either of the outside lines and 220 volts between outers. The company has found that with the load well balanced considerable saving in secondary copper results from the three-wire method of operation.

Each transformer is connected to the primary main through outside-type primary fuses of double the transformer rating in amperes. The secondary network is sectionalized between each pair of transformers by a set of fuses or junction cut-outs. These are placed approximately at the point of zero current between the adjacent transformers on each secondary section. (See Fig. 105.) The object of this fusing of secondary sections is to prevent the transformers on either side of a defective unit or secondary service from assuming heavy overloads. As soon as any abnormal conditions occur the junction fuses on either side of a defective section blow, as well as the primary fuses on the transformers, and the section is automatically cleared from the system. The junction fuses are of copper wire, being about 50 per cent. larger than the rating of the smaller of the two transformers between which they are in each instance placed, and varying from about 60 amp. between 5-kw. transformers to 400 amp. between 50-kw. units. No fuses are installed in the neutral lines of the secondary networks, although fuses are placed in all leads running from any wire of the secondary service to consumers' premises. The secondaries are grounded; see **138.**

132. **Three-phase low-voltage distribution systems** are largely used in industrial plants. The generated voltage is either 220 or

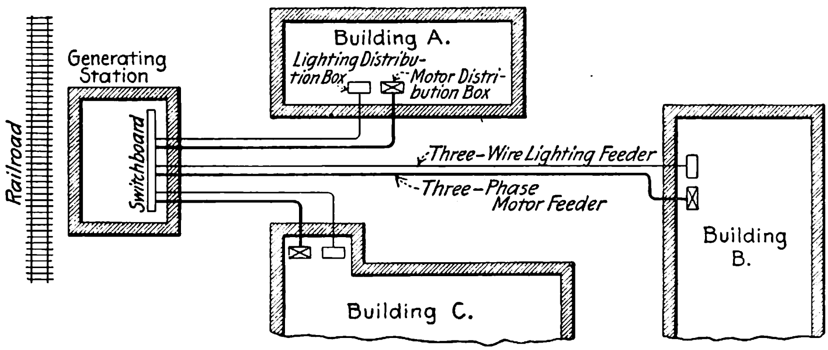


FIG. 106.—Three-phase individual feeder layout.

440. It is probable that 220 is to be preferred inasmuch as 440 is too high a voltage for safety around cranes and other motored machines in a shop. Figs. 106 and 107 illustrate what is probably the best lay-out for a three-phase industrial-plant system. Individual-motor feeders operate at either 220 or 440 volts and three-wire, single-phase lighting feeders at 110 and 220 volts are supplied through balance coils. (See section on *Transformers.*) The lighting load must be reasonably well-balanced among the phases. Any of the schemes of distribution suggested in Figs. 93 to 99 could be used with the three-phase system, but that of Figs. 106 and 107 is probably the best. Where balance coils are not used, single-phase incandescent-lamp circuits can be taken from three-phase circuits as suggested in Fig. 108. The lamp load should be balanced among the phases. However, any series-multiple scheme of connecting incandescent lamps should be avoided

and incandescent lamps should always, where possible, be operated at 110 volts. (See *First Section*, Index.) Occasionally it is advisable to carry the lighting feeders three-phase to the building or group of buildings served and to the balance coils, providing three-wire circuits are installed within the buildings. See also section on *Transformers*.

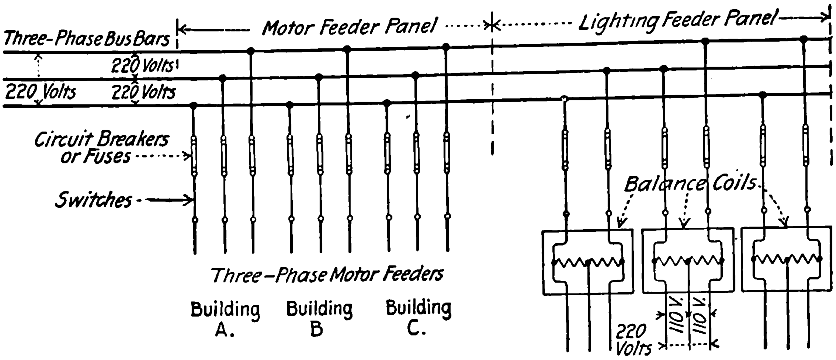


FIG. 107.—Connections at three-phase switchboard.

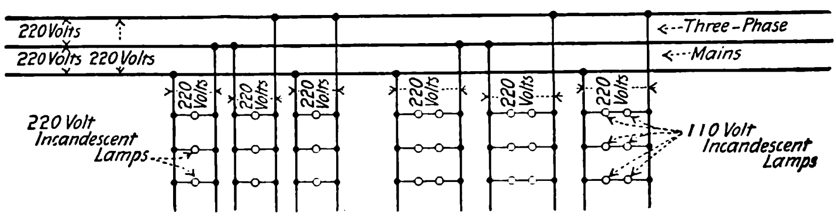


FIG. 108.—Single-phase lighting circuit from three-phase circuit. (*Note.*—Where two lamps are shown connected in series across 220 volts, 110-volt lamps must be used.)

133. **Three-phase, high-voltage distribution** (Fig. 109) is used considerably for municipalities and is probably the best method for average conditions. The voltage for three-wire three-phase systems is almost always 2,200 so that standard transformers can be used. Where a four-wire three-phase system is used the voltage between outer wires is, approximately, 3,800, but the voltage from any one of the outer wires to the neutral wire is 2,200 so standard transformers can be used. Single-phase transformers are used to serve the lighting loads. The transformers are so distributed on the three phases that the total load on the generator is approximately balanced. The secondaries of the lighting transformers are connected as are those of a system with single-phase primary conductors and may, as suggested in Fig. 102, be either two-wire or three-wire. All three wires of the three-phase circuit are not carried to all parts of the district served. Where the load is not dense only two wires—giving a single-phase circuit—are used. (See Fig. 109.)

Motors exceeding 5 h.p. in capacity should be at least 220-volt and should be three-phase rather than single-phase and separate

services should be provided for motors exceeding 1 h.p. in capacity. The methods of connecting transformers served by a three-phase system are given in the section on *Transformers*. It is best practice to provide individual feeders and mains for the motor and the lighting loads, but this cannot always be done. The three-phase four-wire distribution system (Fig. 110) is used in several of the larger cities. Its advantage is that it saves copper as the transmission voltage is 3,800 rather than 2,200. For further information see section on *Transformers*.

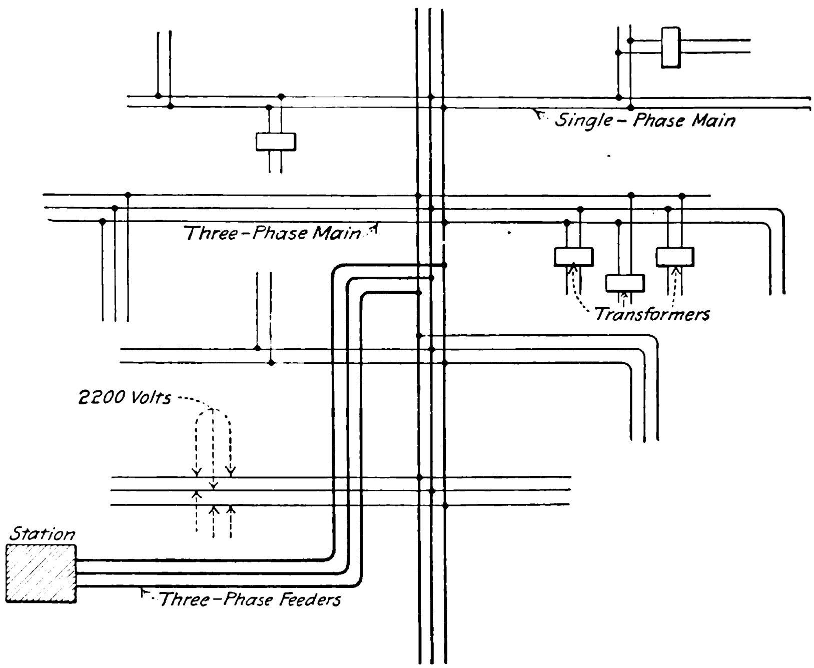


FIG. 109.—Three-phase feeder and mains in a municipality.

134. Protection and Switches on Distribution Systems.—In 131 a description is given of the methods used for overload protection for the overhead three-wire secondary network used in Denver, Colo. In general, it may be said that it is the practice of practical operating men to use but very few fuses or other protective cut-outs in overhead distribution systems. Where at all feasible, branch circuits are tapped to main circuits with soldered joints or with a disconnective pot-head. Fuses are used as seldom as possible because it has been found that they make more trouble than they are worth. Porcelain high-tension fuse blocks are almost invariably interposed in the primary leads to distributing transformers to protect the transformer against overload.

Fig. 111 suggests the practice sometimes followed for protecting alternating-current distribution systems against overload. Fuses are used only on unimportant mains. They are not used at important points because they are apt to rupture at the wrong

time. A short-circuit on one of the principal conductors will usually burn itself clear and throw the station circuit-breaker simultaneously, so restoring the breaker restores service. If it does not burn itself clear it is necessary to send a man out to open the disconnectives in succession until the fault is located. This method has been found superior to one involving the use of many fuses.

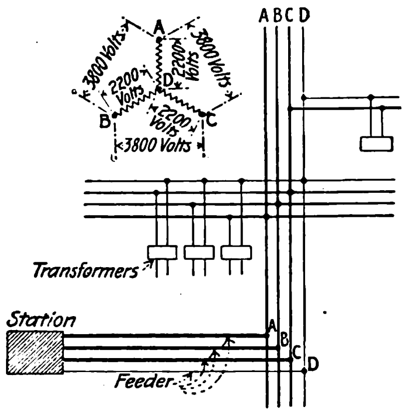


FIG. 110.—Three-phase four-wire distribution system.

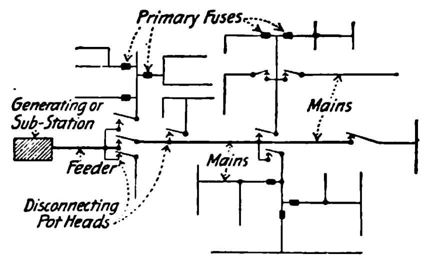


FIG. 111.—Overload protection on alternating-current overhead distribution.

In networks, such as that of Fig. 103, usually, each conductor is, fused wherever it joins another so that any faulty section will "burn itself clear." Copper fuses—stamped sheet metal or wire—are best for this service.

In industrial plants, where the Underwriters have jurisdiction, all conductors must be fused in accordance with the code rules which require protection wherever a conductor changes in size from large to small. (See *Fuses*, Index.)

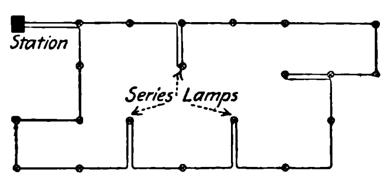


FIG. 112.—Open loop series circuit.

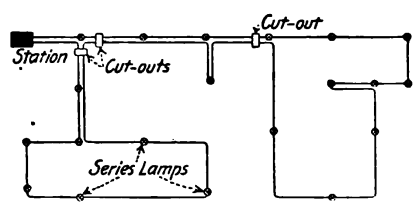


FIG. 113.—Mixed loop series circuit.

135. **Series circuits** (see "*Fundamentals*" section, Index, for further information) are used for series arc and incandescent lighting and for fire-alarm and watchman's circuits.

136. **In laying out a series circuit** the open-loop system of distribution (Fig. 112) can be used if the circuit covers a relatively small area. If a large area is covered the system suggested in Fig. 113 should be used because with it, if an open-circuit occurs in some section, the section can be quickly isolated by throwing the cut-out switch at the point where the section joins the main circuit. Series cut-out switches, especially designed, can be purchased from

electrical supply dealers. Obviously the open-loop plan requires a minimum of poles and wire, hence is the most economical to install. When laying out series circuits consideration should be given to future additions of lamps to the series circuit and the circuit should be so routed that they can be included with the least expense. These notes apply for either series incandescent or series arc-lighting circuits.

137. Series Circuits on Pole Lines (*From report of Committee on Overhead Line Construction, National Electric Light Association*, 1911).—Every series circuit should start from station, substation, or other point of distribution, on a given pin and cross-arm, and follow the same relative pin and cross-arm throughout its course. Circuits should not jump from one location on a cross-arm to another location on the same cross-arm, nor to a different cross-arm, but should always be placed on their proper pin. Such a system renders trouble hunting and repair work much simpler than they otherwise would be and is the only possible way in which circuits can be constructed, maintained, operated and extended in a satisfactory systematic manner. As series arc and series incandescent circuits are cut dead during the daytime and will not, therefore, hamper linemen working on a pole, these circuits can often be run to advantage on the pole-pins of the cross-arm. Such an arrangement is also convenient for making lamp loop connections. As it is usual practice to ground all constant-current series circuits in the station, these wires should be considered as grounded by linemen when working on the poles, this in addition to the general rule that all wires should be treated as being alive at all times.

138. Alternating-current, low-voltage, secondary circuits should be grounded. This is the recommendation of the National Electrical Code and the practice of progressive central station companies. Grounding prevents accidents to persons and damage, by fire, to property. If some point of a low-voltage secondary circuit is grounded, no point of the circuit can rise above its normal potential (except under unusual conditions) in case of a breakdown between primary and secondary windings of the transformer, or of other accidental connection between the primary and secondary circuits.

If the secondary is not grounded and the transformer breaks down, the primary voltage is impressed on the secondary circuit. A person touching any bare part of the secondary circuit would probably receive the primary voltage if he were grounded by contact with, say, a radiator or a gas fixture. Furthermore, the secondary not being grounded and there being a ground on the primary circuit, the primary voltage impressed on the low-voltage fittings of the secondary circuit might cause a fire. With the secondary grounded, a transformer breakdown will often reveal itself through the blowing of the primary fuses. Where a normal voltage in excess of 250 is possible between any wire of a secondary circuit and ground, it is doubtful whether the secondary should be grounded, because shocks to ground from such a system might cause death. See The National Electrical Code for further information regarding grounding.

139. Ground connections can be made in many ways. They may be made inside of buildings by connecting to pipes or may be installed at the poles which support the transformers or the secondary networks. Central-station practice favors grounds at poles. Figs. 114 and 115 show the method of making a pole ground used by the Allegheny County Light Company. The lower end of the pipe is pointed, the upper end is "tinned" inside and the wooden plug is inserted in the upper end of the pipe in the Company's shop. In making a ground, the pipe is driven into the earth next to the

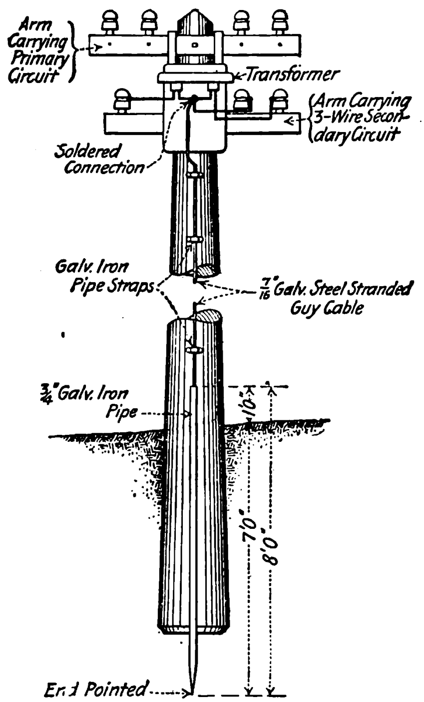


FIG. 114.—Method of grounding secondary circuit.

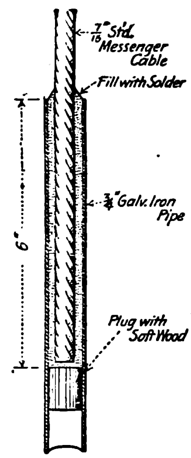


FIG. 115.—Method of connecting cable to pipe.

pole and the steel-cable ground conductor, its end having been tinned, is soldered into the upper end of the pipe by pouring molten solder in around it. An excellent feature of this method is that the $\frac{7}{16}$-in. ground conductor is so strong that it will never be disturbed. It is secured to the pole with pipe straps. (See **140**.)

The ground-pipe cap illustrated in Fig. 116 is used by several large central-station companies for connecting the ground wire to the ground pipe. Soldering is not necessary. The cap with the wire in position is placed over the top of the pipe and the pipe driven. In driving, the wire is firmly wedged between the cap and the pipe. The cap protects the top of the pipe. The cap fits $\frac{1}{2}$-in. pipe or $\frac{3}{4}$-in. rod, with a No. 6 ground wire. Where No. 4 wire is used, it is not necessary to double it. Ground pipes must be long enough to reach permanently moist soil, and in driving care must be taken not to drive them into the pole and thereby insulate them. Some

companies ground to fire hydrants. The ground wire is supported down the pole by cleats or straps, and carried in a trench possibly 18 in. deep, to the fire hydrant. It is connected thereto by clamping it under a footing bolt. In Denver this method costs $4.50 per ground, the average length of ground wire required from pole top to ground being 60 ft.

140. Ground wires should be incased by wooden molding, for a distance of at least 7 ft. from the surface, to protect against shocks to passersby. Under certain conditions of soil moisture, a shock can be received from a ground wire by a person standing on the earth's surface. The ground pipe extends about a foot above ground and is not usually protected. Some companies incase the entire length of the ground wire in molding to protect the linemen.

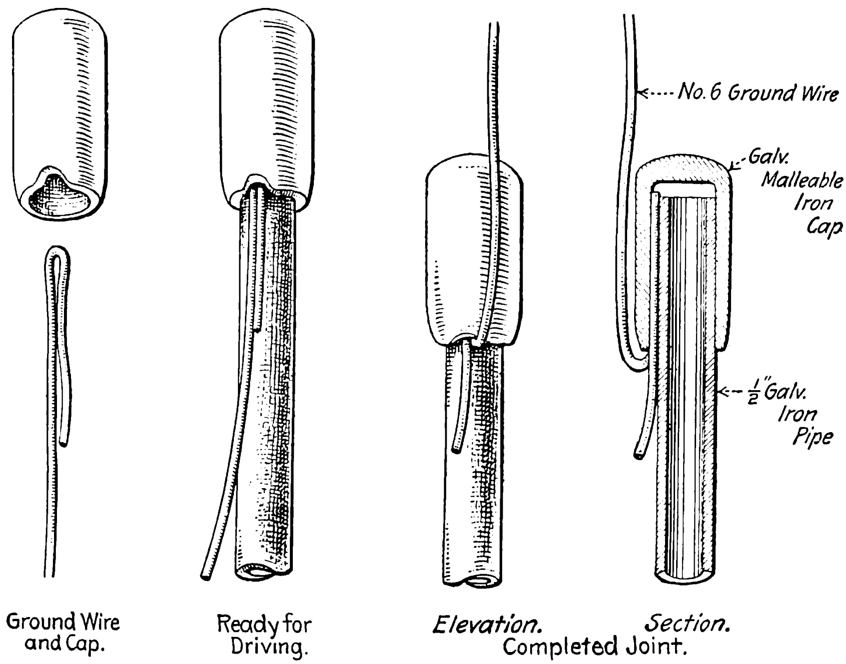


FIG. 116.—Making connection with ground-pipe cap.

No copper wire smaller than No. 6 should be used for a ground wire and some companies use nothing smaller than No. 4. Copper wire is preferable. Bare wire is satisfactory and should be attached to the poles with cleats or straps. Staples, although used, should not be. The National Electrical Code requires for three-phase systems that the ground wire be of the same carrying capacity as any one of the three mains. There should be a ground for each transformer or group of transformers, and when transformers feed a network with a neutral wire, there should, in addition, be a ground at least every 500 ft.

141. Ground-wire connections to transformer secondaries should be made to the neutral point or wire if one is accessible. Where no neutral point is accessible, one side of the secondary

circuit may be grounded, provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 250 volts (*National Electrical Code*). Fig. 117 shows theoretical diagrams of ground connections to transformer

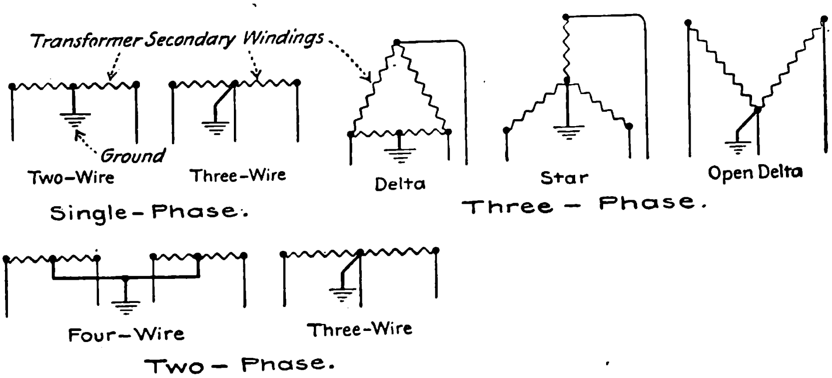


FIG. 117.—Theoretical diagrams of secondary ground connections.

secondaries and Fig. 118 illustrates how some of these connections are arranged with commercial transformers. The neutral point of each transformer feeding a two-phase, four-wire secondary, should be grounded, unless the motors taking energy from the

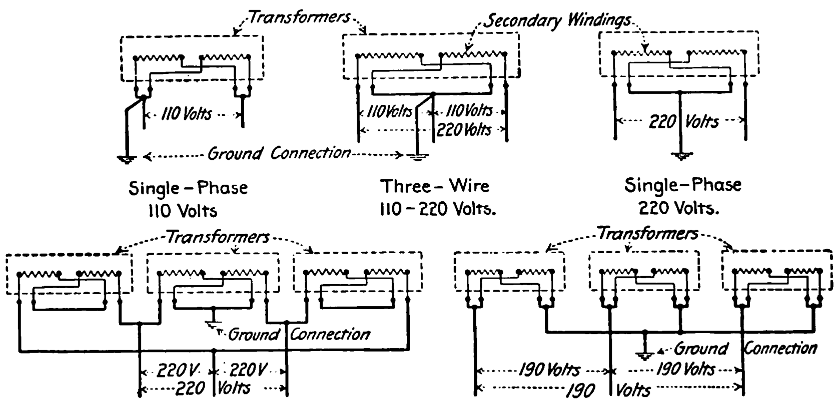


FIG. 118.—Ground connections to secondaries of commercial transformers.

secondary have interconnected windings. Where they are interconnected, the center or neutral point of only one transformer is grounded. No primary windings are shown in Figs. 117 and 118. Fig. 118 the secondary winding of each transformer is shown divided into two sections, as it is in commercial transformers.

SECTION IV

INTERIOR WIRING

GENERAL

1. The National Electrical Code Rules, the recommendations of The National Fire Protection Association, should be followed in installing all interior wiring. These rules are revised every two years (odd-numbered years) so it is inadvisable to include them in this book. A copy of these rules can be obtained by applying to any local fire inspection bureau or to The Underwriters' Laboratories, Chicago, Ill. The Factory Mutual Fire Insurance Companies of 31 Milk St., Boston, Mass., publishes an illustrated edition of the rules. The author's "*Wiring for Light and Power,*" in addition to being a general treatise on the wiring of buildings, contains the National Electrical Code and much data in explanation thereof.

2. There are local regulations covering the installation of wiring, in force in many localities, which have been enacted by city or state governments. Sometimes these differ from the National Code regulations so it is always well to be familiar with all of the regulations in force before starting any work. The city and state rules are in reality laws and therefore take precedence over the *National Electrical Code Rules* which have no legal status.

3. General Suggestions (*Factory Mutual Fire Insurance Rules*).—In all electric work, conductors, however well insulated, should always be treated as bare to the end that under no conditions existing or likely to exist, can a ground or short-circuit occur, and so that all leakage from conductor to conductor, or between conductor and ground, may be reduced to the minimum. Special attention must be paid to the mechanical execution of the work. Careful and neat running, connecting, soldering, taping of conductors, and securing and attaching of fittings, are specially conducive to security and efficiency.

In laying out an installation, except for constant-current systems, every reasonable effort should be made to locate distribution centers in easily accessible places, at which points the cutouts and switches controlling the several branch circuits can be grouped for convenience and safety of operation. The load should be divided as evenly as possible among the branches, and all complicated and unnecessary wiring avoided. The use of wire-ways for rendering concealed wiring permanently accessible is most heartily endorsed and recommended; and this method of accessible concealed construction is advised for general use.

4. Inside Wiring Rules in Brief (*Factory Mutual Rules*).—Rubber-covered wire must be used in all damp places, in all conduit, molding, or concealed work, and throughout all systems on which the voltage exceeds 550. For "open" work in dry places where the voltage is not over 550, slow-burning wire is recommended, as it fulfills ever requirement for such work, is less expensive and will not carry fire. This wire has special merit for use in linty and

dusty places, for lint does not readily adhere to the hard, smooth, outer surface, as is the case with wires having a weather-proof braid on the outside which in warm rooms becomes sticky. Moreover, what little lint may collect upon it can be easily brushed off, so that when "sweeping down" there is much less liability of breaking the insulators or badly deranging the wires.

Where of necessity a considerable number of "open" wires are brought close together as, for example, about the ordinary distributing switchboard, the wires should have either the slow-burning insulation as just described, or if a rubber insulation is necessary it should be protected by a heavy "slow-burning" outer braid. The weather-proof and rubber insulations in common use contain a large amount of inflammable material, which ignites easily and produces a fierce fire and dense smoke. It is therefore desirable to reduce, as far as possible, the amount of this inflammable material and to surround it with a tight, "slow-burning" cover to prevent rapid combustion. To still further reduce the amount of combustible material, the porcelain insulators by which the wires are held in place may be supported on an iron frame.

Before beginning work the circuits should be carefully mapped out and the work so planned as to secure the very simplest arrangement.

In mill work, "open" wiring securely supported on porcelain insulators is generally best. Mains of No. 8 B. & S. gage wire and larger are usually most conveniently carried through space from timber to timber and supported at each timber only. Smaller wires thus supported would be liable to be broken, and should therefore be wrapped around the beams or carried through them in holes bushed with porcelain, or they may be fastened to strong running-boards, well put up. The idea is to have the wires so rigidly supported on proper insulators that, even if they were bare, the insulation of the system would be perfect. All joints should be securely made and then carefully soldered and taped.

Wires should be carefully protected where liable to be deranged or injured, as in passing from story to story up side walls or columns, or near belts, or over shelves and similar places where anything is likely to be piled against them. Excellent protection can be secured by carrying them through iron pipe, first reinforcing the insulation of each wire by enclosing it in flexible insulating tubing (also referred to as "standard flexible tubing") unless the wire is double braided rubber covered in which case the insulating tubing is unnecessary. On alternating-current systems, the two or more wires of the same circuit should be run in the same pipe to avoid induction effects. (See Figs. 56 and 57.) Even on direct-current systems this arrangement is best, as then the expense and inconvenience of re-wiring is avoided when it is desired to change such systems to alternating current which frequently happens. Protection may also be obtained by strong wooden boxing, with a slanting top to keep out dirt, the holes through which the wires enter the top being bushed with short porcelain tubes. (See Fig. 56.)

The use of incandescent lamps in series on constant-potential systems is not approved.

5. Brief of Underwriters' Rules for Wiring in Especially Hazardous Places (such as Picker and Carding Rooms, Napping Rooms, Dust Chambers, Etc.) (*Factory Mutual Wiring Rules*).—For incandescent lamps in these more hazardous places, an excellent pendant can be secured by using reinforced flexible cord and a keyless socket with an outlet threaded for $\frac{3}{8}$-in. pipe and properly bushed, as advised for "Portable Lamps" in **6.** The cord should be securely supported from the ceiling by a porcelain cleat or split knob, and the two conductors should then be separated and soldered to the overhead circuit. (See Fig. 76.) The regular "Water-proof Pendant" described in **98** could also be used. As far as possible cut-outs should not be located in these rooms, but if this cannot be avoided they should be of the plug or cartridge type and should be enclosed in dust-tight cabinets of approved construction. (See Code rules governing the construction of dust-proof switch cabinet.) If it is desired to control the lights from points in these rooms, it should be done by snap switches, which should be either enclosed in dust-tight cabinets or located where lint and flyings cannot accumulate around them.

Drop cords can be effectively supported from a ceiling with the ceiling buttons shown in Fig. 76A. The cord is passed through the hole in the button and then soldered to the conductors that feed it. Some inspectors consider the ceiling button a much better support at a ceiling than either a rosette or a split knob. Knobs are not generally considered good supports for flexible cord. Ceiling buttons are particularly desirable in industrial plant work because there is no chance for the conductors to get loose from them. Where a drop cord is subject to vibration it should always be soldered to the conductors that feed it. If the connection is effected with the screw clamps of a rosette, the vibration is likely to loosen the screws and cause a loose connection.

6. Brief of Underwriters' Rules Covering the Arrangement and Use of Portable Lamps (*Factory Mutual Fire Insurance Company's Wiring Rules*).—In this class of work the fittings are subjected to much hard usage, and the very best possible construction is therefore necessary. Instead of the ordinary flexible cord made for pendant lamps, a special cord having an extra covering of rubber, reinforced by a tough outer braid, should be used. (See *Section I* for dimensions of this cord.) The cord should be securely fastened to the wall or ceiling by a cleat or split knob near the point at which it connects to the rosette or supply wires, so that no strain can come on this connection. (See Fig. 76.) It should also be knotted inside the socket, as explained elsewhere. An approved metal shell socket with an outlet threaded for $\frac{3}{8}$-in. pipe should be used, so that the whole cable may be drawn into the socket and still permit the use of a proper socket bushing.

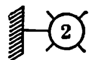
The bulb of an incandescent lamp frequently becomes hot enough to ignite paper, cotton and similar readily ignitible materials, and in order to prevent it from coming in contact with such materials, as well as to protect it from breakage, every portable lamp should be surrounded with a substantial wire guard. Many of the lamp-

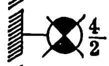
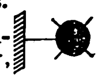
STANDARD SYMBOLS ADOPTED BY THE NATIONAL CONTRACTORS' ASSOCIATION AND THE AMERICAN INSTITUTE OF ARCHITECTS

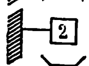
(Copyrighted by the National Contractors' Association.)

 Ceiling outlet; electric only. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

 Ceiling outlet; combination. $\frac{4}{2}$ indicates 4-16 c-p. standard incandescent lamps and 2 gas burners. If gas only, 

 Bracket outlet; electric only. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

 Bracket outlet; combination. $\frac{4}{2}$ indicates 4-16 c-p. standard incandescent lamps and 2 gas burners. If gas only, 

 Wall or baseboard receptacle outlet. Numeral in center indicates number of standard 16 c-p. incandescent lamps.

 Floor outlet. Numeral in center indicates number of Standard 16 c-p. incandescent lamps.

 Outlet for outdoor standard or pedestal, electric only. Numeral indicates number of standard 16 c-p. incandescent lamps.

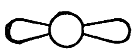
 Outlet for outdoor standard or pedestal; combination. $\frac{6}{6}$ indicates 6-16 c-p. standard incandescent lamps; 6 gas burners.

 Drop cord outlet.

 One-lamp outlet, for lamp receptacle.

 Arc lamp outlet.

 Special outlet for lighting, heating and power-current, as described in specifications.

 Ceiling fan outlet.

S^1 S. P. switch outlet.

S^2 D. P. switch outlets.

S^3 3-way switch outlet.

S^4 4-way switch outlet.

S^D Automatic door switch outlet.

S^E Electrolier switch outlet.

Show as many symbols as there are switches. Or in case of a very large group of switches, indicate number of switches by a roman numeral, thus; S' XII; meaning 12 single pole switches.

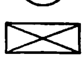
Describe type of switch in specifications, that is, flush or surface, push button or snap.

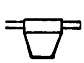
 Meter outlet.

 Distribution panel.

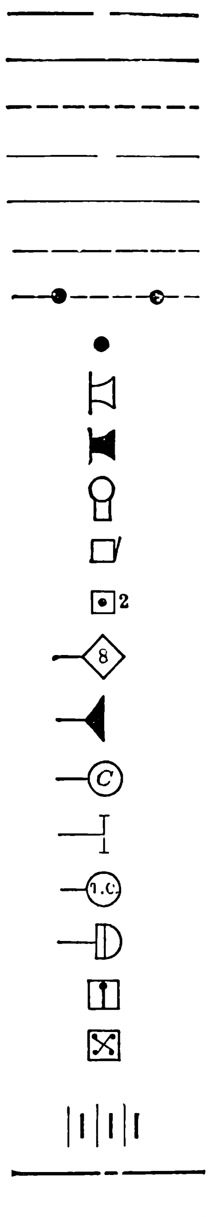
 Junction or pull box.

 Motor outlet. Numeral in center indicates horsepower.

 Motor control outlet.

 Transformer.

STANDARD SYMBOLS ADOPTED BY THE NATIONAL CONTRACTORS' ASSOCIATION AND THE AMERICAN INSTITUTE OF ARCHITECTS.—*Continued*



Main or feeder run concealed under floor.

Main or feeder run concealed under floor above.

Main or feeder run exposed.

Branch circuit run concealed under floor.

Branch circuit run concealed under floor above.

Branch circuit run exposed.

Pole line.

Riser.

Telephone outlet; private service.

Telephone outlet; public service.

Bell outlet.

Buzzer outlet.

Push button outlet. Numeral indicates number of pushes.

Annunciator. Numeral indicates number of points.

Speaking tube.

Watchman clock outlet.

Watchman station outlet.

Master time clock outlet.

Secondary time clock outlet.

Door opener.

Special outlet for signal systems, as described in specifications.

Battery outlet.

Circuit for clock, telephone, bell or other service, run under floor, concealed. Kind of service wanted ascertained by symbol to which line connects.

Circuit for clock, telephone, bell or other service, run under floor above, concealed. Kind of service wanted ascertained by symbol to which line connects.

Heights of center of wall outlets (unless otherwise specified):

Living Rooms	5 ft. 6 in.
Chambers	5 ft. 0 in.
Offices	6 ft. 0 in.
Corridors	6 ft. 3 in.
Height of switches (unless otherwise specified)	4 ft. 0 in.

FIG. 1.—Standard Wiring Symbols.—*Continued.*

guards now on the market are very flimsy and utterly worthless.

7. **Light Wiring in Industrial-plant Storehouses** (*Factory Mutual Rules*).—The best and safest light for storehouses is the incandescent lamp. Special care should be taken to so locate and protect the wires that the handling of storage in the building could never derange them. The pendants should be of the type advised for "Especially Hazardous Places" in **5**. The cut-outs and switches should be grouped and enclosed in dust-tight cabinets of approved construction. (See **48**.) Standard lamp-guards should be provided, as advised for "Portable Lamps" in **6**.

8. **Fire Light Wiring in Industrial Plants** (*Factory Mutual Fire Insurance Company's Wiring Rules*).—It is a good plan, where possible, to arrange in yards and buildings, on circuits entirely out of the way of ladders or fire streams, a few lights which may be thrown on at the time of a fire when the main lights are off, enabling firemen to move about quickly and safely.

Such lights can generally be best arranged on entirely separate circuits, and will often be useful for repair work and for lighting the help into and out of the mill, when the main lights are off. These circuits may take current from a small, separate generator, driven by an independent engine or waterwheel; or from outside lines; or possibly from a storage battery, so isolated from the main buildings as not to be affected by a fire in them.

9. **Application of Flexible Cord.**—With the exception of wet rooms, storehouses, and specially hazardous rooms of textile mills and the like, flexible cord may be used for pendants hanging freely in the air. If the lamp is to be moved about, so that the cord is liable to come in contact with surrounding objects, reinforced flexible cord like that described for "Portable Lamps" should be provided. The two conductors which form the cord should be carefully knotted together, as shown in Fig. 9, in both socket and rosette, to prevent any strain from coming on the small binding screws in these fittings. The entire weight of the socket and lamp should be assumed, by some approved method, so that all mechanical strain is removed from electrical joints and binding screws.

10. **The standard wiring symbols** adopted by the National Contractors' Association and the American Institute of Architects are given in Fig. 1. These are quite generally used.

WIRING FITTINGS AND MATERIALS

11. **Wire nails** are formed from steel wire of the same diameter as the shank of the nail is to be. Ordinary nails have a "bright" finish. Copper, brass and galvanized steel nails can be obtained. The wire from which nails are made, hence the nail diameters are measured by the American Steel & Wire Co's. Gage (see table in *Section I*) which is the same as the Washburn & Moen gage, and which is used by practically all nail manufacturers, though it is sometimes given a different name. Some of the principal wire manufacturers have decided to call it the United States Steel Wire Gage.

12. Dimensions of Casing, Finishing, Shingle and Fine Nails

(American Steel & Wire Company)

Nail diameters are measured by the A. S. & W. gage. See Section I for table. Equivalent B. & S. gage numbers and inch fractional equivalents are given in Table 12.

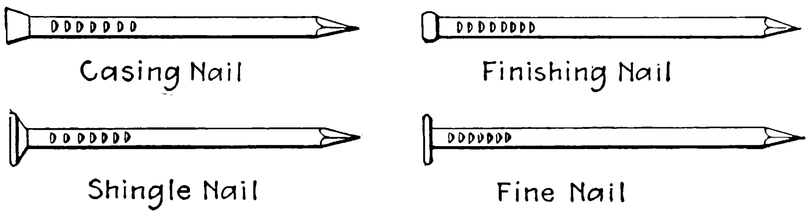


FIG. 2.—Casing, finishing, shingle and fine nails.

Size	Length, inches	Casing		Finishing		Shingle		Fine	
		Gage	Approx. No. per pound	Gage	Approx. No. per pound	Gage	Approx. No. per pound	Gage	Approx. No. per pound
2 d	1	15½	1,010	16½	1,351	.....	....	16½	1,351
3 d	1¼	14½	635	15½	807	13	429	[2]15	778
3½ d	1⅜	.....	....	.....	....	12½	345	.....	....
4 d	1½	14	473	15	584	12	274	14	473
5 d	1¾	14	406	15	500	12	235	.....	....
6 d	2	12½	236	13	309	12	204	.....	....
7 d	2¼	12½	210	13	238	11	139	.....	....
8 d	2½	11½	145	12½	189	11	125	.....	....
9 d	2¾	11½	132	12½	172	11	114	.....	....
10 d	3	10½	94	11½	121	10	83	.....	....
12 d	3¼	10½	87	11½	113	.....	....	.....	....
16 d	3½	10	71	11	90	.....	....	.....	....
20 d	4	9	52	10	62	.....	....	.....	....
30 d	4½	9	46	.....	....	.....	....	.....	....
40 d	5	8	35	.....	....	.....	....	.....	....
[1]2 d	1	.....	....	.....	....	.....	....	17	1,560
[1]3 d	1⅛	.....	....	.....	....	.....	....	16	1,015

[1]These sizes are called "Extra Fine."
[2]This nail is only 1⅛ in. long.

13. Wood Screws.—Diameters are measured by the American Screw Company's Gage (see Wire Gage Table in Section I), and range in size from No. 0 to No. 30. They range in length from ¼ in. to 6 in. The increase in length is by eighths of an inch up to 1 in., then by quarters of an inch up to 3 in. and by half inches up to 5 in. Manufacturers' standards vary, but generally the threaded portion is approximately seven-tenths of the total length. There is no standard number of threads per inch for the products of all manufacturers.

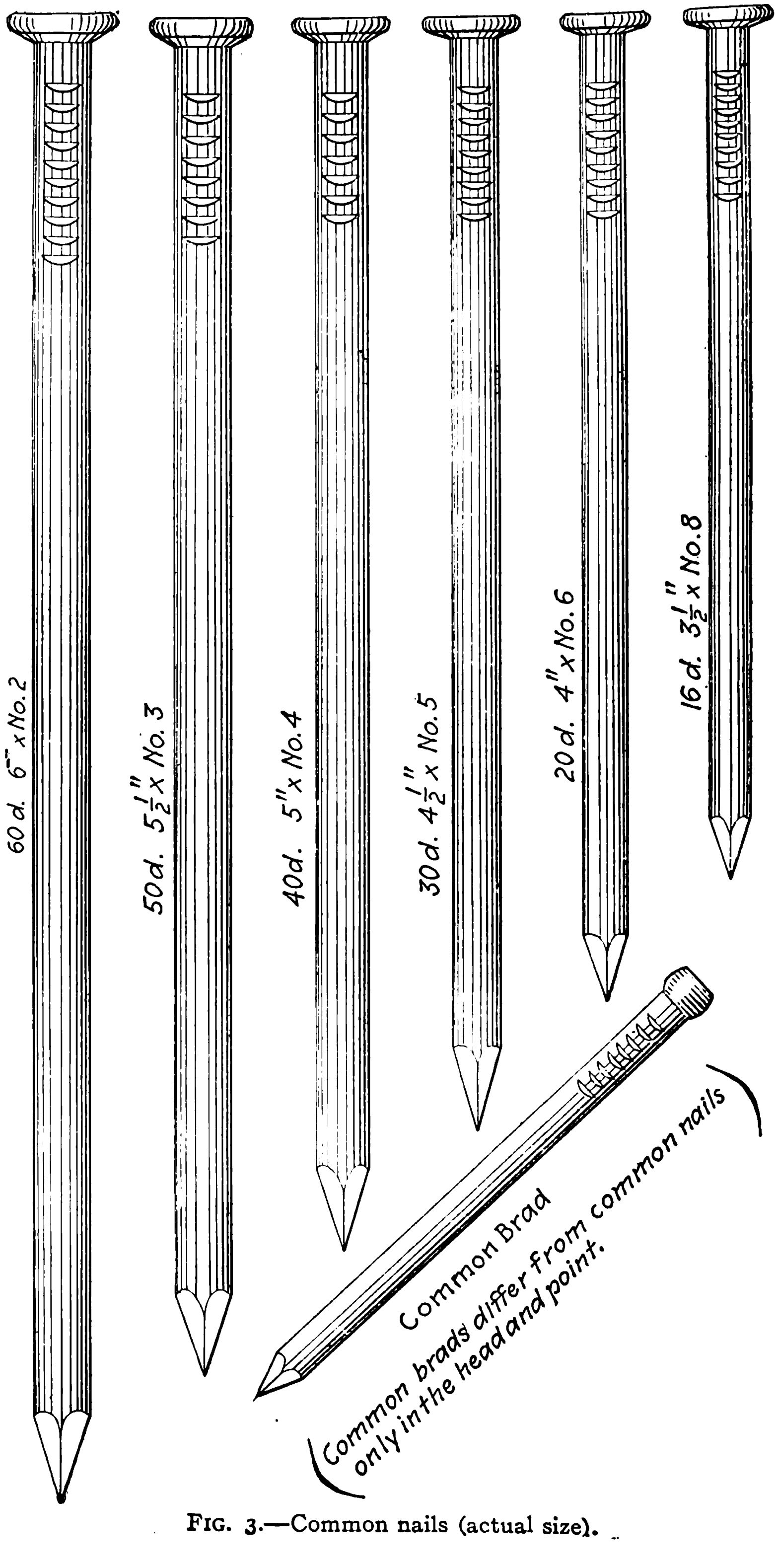


FIG. 3.—Common nails (actual size).

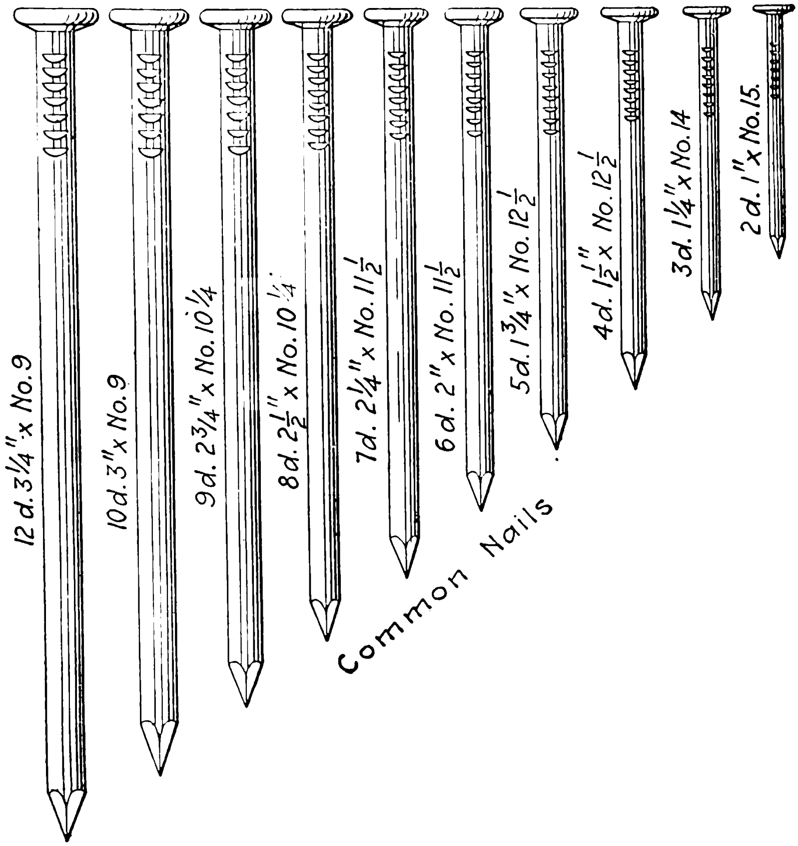


FIG. 3A.—Common nails (*Continued*).

14. Dimensions of Common Nails and Brads

(American Steel & Wire Company)

Size	Length, inches	A. S. & W. gage No.	Approx. No. to lb.	Diam. in decimals, inches	Approx. diam. in inches	Nearest B. & S. gage
2d	1	15	876	0.0720	5/64	13
3d	1¼	14	568	0.0800	5/64	12
4d	1½	12½	316	0.0985	7/64	10
5d	1¾	12½	271	0.0985	7/64	10
6d	2	11½	181	0.1130	7/64	9
7d	2¼	11½	161	0.1130	7/64	9
8d	2½	10¼	106	0.1314	1/8	8
9d	2¾	10¼	96	0.1314	1/8	8
10d	3	9	69	0.1483	9/64	7
12d	3¼	9	63	0.1483	9/64	7
16d	3½	8	49	0.1620	5/32	6
20d	4	6	31	0.1920	3/16	6
30d	4½	5	24	0.2070	13/64	4
40d	5	4	18	0.2253	7/32	3
50d	5½	3	14	0.2437	1/4	2
60d	6	2	11	0.2625	17/64	2

15. Dimensions of Wood Screws

Round-head wood screws do not measure full length, but are from $\frac{1}{16}$ in. to $\frac{3}{16}$ in. short. For example: a No. 4 by $\frac{1}{2}$ in. round-head wood screw measures about $\frac{7}{16}$ in. long under the head and a No. 20 by 2 in. screw measures about $1\frac{7}{8}$ in. under the head.

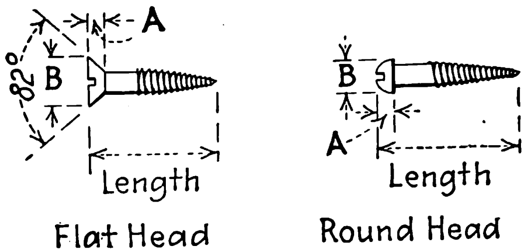


FIG. 4.—Wood screws.

Screw gage No.	Diameter: In decimals	Diameter: In fractions	Diameter: Nearest B. & S. gage	Flat head: A	Flat head: B	Round head: A	Round head: B	Round head: Counter-bore for head		Clearance drill: No.	Clearance drill: Diameter	Greatest length obtainable, inches
0	.05784	$\frac{1}{16}$ −	15	$\frac{1}{16}$	$\frac{7}{64}$ +	. .	. .	. . . . . .	Depth of hole = height of head A	. . . .	. . . . . .	$\frac{3}{8}$
1	.07100	$\frac{5}{64}$ −	14	$\frac{1}{16}$	$\frac{9}{64}$ −	. .	. .	. . . . . .		. . . .	. . . . . .	$\frac{1}{2}$
2	.08416	$\frac{5}{64}$ +	12	$\frac{1}{16}$	$\frac{5}{32}$ +	$\frac{1}{16}$	$\frac{13}{64}$	$\frac{7}{32}$		44	.086	$\frac{7}{8}$
3	.09732	$\frac{3}{32}$ +	11	$\frac{1}{16}$	$\frac{3}{16}$	$\frac{5}{64}$	$\frac{13}{64}$	. . . . . .		. . . .	. . . . . .	$1\frac{1}{2}$
4	.11048	$\frac{7}{64}$ +	9	$\frac{1}{16}$	$\frac{7}{32}$ −	$\frac{5}{64}$	$\frac{13}{64}$	$\frac{7}{32}$		33	.113	$1\frac{1}{2}$
5	.12364	$\frac{1}{8}$ −	8	$\frac{1}{16}$	$\frac{15}{64}$ +	$\frac{3}{32}$	$\frac{15}{64}$	. . . . . .		. . . .	. . . . . .	$2\frac{1}{2}$
6	.13680	$\frac{9}{64}$ −	7	$\frac{5}{64}$	$\frac{17}{64}$ +	$\frac{3}{32}$	$\frac{1}{4}$	$\frac{17}{64}$		28	.1415	3
7	.14996	$\frac{5}{32}$ −	7	$\frac{3}{32}$	$\frac{19}{64}$ −	$\frac{7}{64}$	$\frac{3}{32}$	. . . . . .		. . . .	. . . . . .	3
8	.16312	$\frac{5}{32}$ +	6	$\frac{7}{64}$	$\frac{5}{16}$ +	$\frac{7}{64}$	$\frac{19}{64}$	$\frac{5}{16}$		18	.1695	4
9	.17628	$\frac{11}{64}$ +	5	$\frac{7}{64}$	$\frac{11}{32}$ +		$\frac{21}{64}$	. . . . . .		. . . .	. . . . . .	4
10	.18944	$\frac{3}{16}$ +	5	$\frac{7}{64}$	$\frac{3}{8}$ −	$\frac{1}{8}$	$\frac{11}{32}$	$\frac{23}{64}$		10	.1935	4
11	.20260	$\frac{13}{64}$ −	4	$\frac{1}{8}$	$\frac{25}{64}$ +	$\frac{9}{64}$	$\frac{3}{8}$	. . . . . .		. . . .	. . . . . .	4
12	.21576	$\frac{7}{32}$ −	4	$\frac{1}{8}$	$\frac{27}{64}$	$\frac{5}{32}$	$\frac{25}{64}$	$\frac{13}{32}$		$\frac{7}{32}$	.2188	6
13	.22892	$\frac{15}{64}$ −	3	$\frac{1}{8}$	$\frac{29}{64}$	$\frac{5}{32}$	$\frac{27}{64}$	. . . . . .		. . . .	. . . . . .	6
14	.24208	$\frac{1}{4}$ −	3	$\frac{9}{64}$	$\frac{15}{32}$ +	$\frac{5}{32}$	$\frac{29}{64}$	$\frac{29}{64}$		$\frac{1}{4}$	.250	6
15	.25524	$\frac{1}{4}$ +	2	$\frac{9}{64}$	$\frac{1}{2}$	$\frac{11}{64}$	$\frac{29}{64}$	. . . . . .		. . . .	. . . . . .	6
16	.26840	$\frac{17}{64}$ +	2	$\frac{5}{32}$	$\frac{17}{32}$ −	$\frac{11}{64}$	$\frac{31}{64}$	. . . . . .		. . . .	. . . . . .	6
17	.28156	$\frac{9}{32}$	1	$\frac{5}{32}$	$\frac{35}{64}$ +	$\frac{11}{64}$	$\frac{1}{2}$	. . . . . .		. . . .	. . . . . .	6
18	.29472	$\frac{19}{64}$ −	1	$\frac{11}{64}$	$\frac{37}{64}$	$\frac{3}{16}$	$\frac{17}{32}$	$\frac{35}{64}$		. . . .	.302	6
19	.30788	$\frac{5}{16}$ −	0	$\frac{3}{16}$	$\frac{39}{64}$ −	. .	$\frac{17}{32}$	. . . . . .		. . . .	. . . . . .	6
20	.32104	$\frac{21}{64}$ −	0	$\frac{13}{64}$	$\frac{5}{8}$ +	$\frac{13}{64}$	$\frac{9}{16}$	$\frac{37}{64}$		. . . .	.323	6
21	.33420	$\frac{21}{64}$ +	0	$\frac{13}{64}$	$\frac{21}{32}$	$\frac{13}{64}$	$\frac{19}{32}$	. . . . . .		. . . .	. . . . . .	6
22	.34736	$\frac{11}{32}$ +	0	$\frac{13}{64}$	$\frac{11}{16}$ −	$\frac{7}{32}$	$\frac{5}{8}$	. . . . . .		. . . .	. . . . . .	6
23	.36052	$\frac{23}{64}$ +	2/0	$\frac{7}{32}$	$\frac{45}{64}$ +	$\frac{7}{32}$	$\frac{41}{64}$	. . . . . .		. . . .	. . . . . .	6
24	.37368	$\frac{3}{8}$ −	2/0	$\frac{7}{32}$	$\frac{47}{64}$	$\frac{15}{64}$	$\frac{21}{32}$	$\frac{43}{64}$		. . . .	.377	6
25	.38684	$\frac{21}{64}$ −	3/0	$\frac{7}{32}$	$\frac{49}{64}$ −	$\frac{15}{64}$	$\frac{11}{16}$	. . . . . .		. . . .	. . . . . .	6
26	.40000	$\frac{13}{32}$ −	3/0	$\frac{15}{64}$	$\frac{25}{32}$ +	$\frac{1}{4}$	$\frac{45}{64}$	. . . . . .		. . . .	. . . . . .	6
27	.41316	$\frac{13}{32}$ +	3/0	$\frac{15}{64}$	$\frac{13}{16}$	$\frac{1}{4}$	$\frac{23}{32}$	. . . . . .		. . . .	. . . . . .	6
28	.42632	$\frac{27}{64}$ +	3/0	$\frac{1}{4}$	$\frac{27}{32}$	$\frac{1}{4}$	$\frac{47}{64}$	. . . . . .		. . . .	. . . . . .	6
29	.43948	$\frac{7}{16}$ +	4/0	$\frac{1}{4}$	$\frac{55}{64}$ +	$\frac{17}{64}$	$\frac{3}{4}$	. . . . . .		. . . .	. . . . . .	6
30	.45264	$\frac{29}{64}$	4/0	$\frac{17}{64}$	$\frac{57}{64}$	$\frac{9}{32}$	$\frac{25}{32}$	. . . . . .		. . . .	. . . . . .	6

16. Toggle bolts, which are used for fastening molding and electrical devices to hollow tile or plaster-on-metal-lath surfaces, are of two general types. The screw type (Fig. 5) is the most frequently used but has the disadvantage that if it is ever necessary to entirely remove the screw, the toggle is lost within the wall. Where the object fastened must be removed and replaced a nut-type toggle bolt (Figs. 6 and 7) can be used. With that of Fig. 6 it is usually necessary, after the device is in place, to cut off the part of the bolt that extends so that the thing will look well. The so-called plumber's toggle bolt (Fig. 7) has a removable, hexagonal cap so that the device can be inserted in the wall before the object to be fastened is slipped over the bolt. Then, on putting the cap in place, the whole bolt is backed into the wall, hiding the surplus

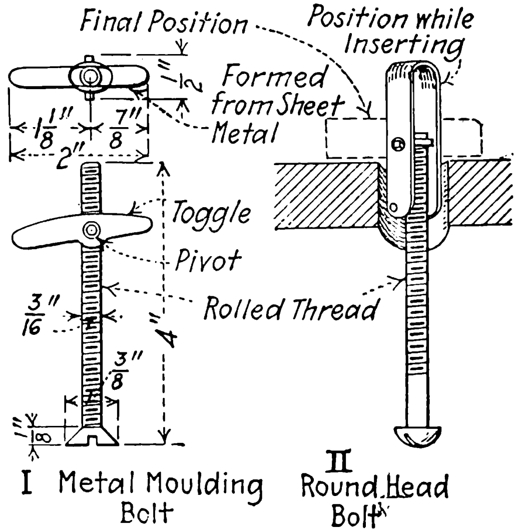


FIG. 5.—Screw-type toggle bolts.

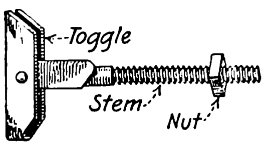


FIG. 6.—Nut-type toggle bolt.

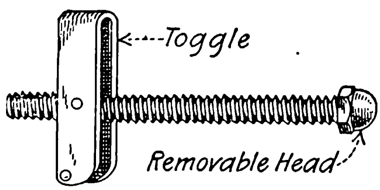


FIG. 7.—Plumbers' toggle bolt.

thread from view. Cone-head toggles, Fig. 8, are used principally for the erection of metal molding and have the advantage that the toggle head will readily pass through the hole in the molding backing. Toggle bolts are made in several diameters and lengths. That of Fig. 5, *I* and Fig. 8 are made by the National Metal Molding Co., Pittsburg. The others illustrated are made by the Chicago Nut Co., Chicago, Ill.

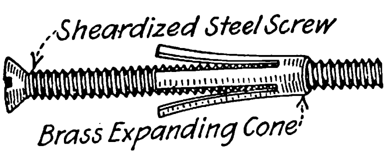


FIG. 8.—Toggle bolt for metal molding.

16A. Knobs, the small porcelain insulators used for supporting interior conductors, are of two general types, the solid (Fig. 8, B) and the split (Fig. 8, A). The solid knob is required by the Underwriters for certain work and is the cheaper of the two, but the additional cost of the tie-wire required with it and the labor of tying

makes the cost installed about equal to that of the split knob. The split or confining knob is unquestionably superior to the solid knob, as no tie-wires are required with it. In some places inspectors require with the larger size wires that a tie-wire be used even with the split knob, because Code rules specify tie-wires. The rule is not always strictly enforced. Knobs of the same kinds are used for both open and for knob and tube wiring.

16B. As to the Use of Screws or Nails with Split Knobs.—Nails hold better than screws in certain woods. The breaking of knobs at the time of putting them up with screws is not the only source of trouble, for the binding tension applied often acts to crack the knob a considerable time after it has been put in place. It is an objectionable practice of many wiremen in putting up knobs with screws to drive the screws in nearly all the way with a hammer, giving them only a couple of turns with a screwdriver to tighten them. The principal argument in favor of the use of the nail is the great saving of the wiremen's time that results as compared with that required for putting in screws. The insulating value of either construction is practically the same.

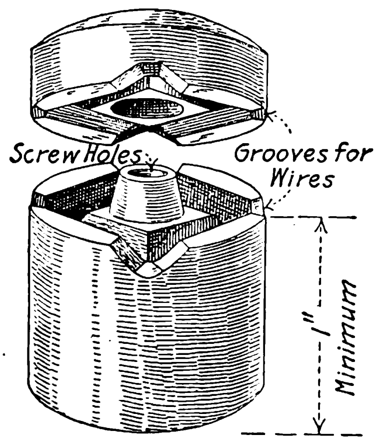


FIG. 8A.—Split knob.

16C. A split knob which clamps the conductor between its two halves is shown in Fig. 8, A. Split knobs must be used for conductors smaller than No. 8, B. & S. gage.

16D. Dimensions of Standard Porcelain Knobs

(*R. Thomas & Sons Company*)

All dimensions are in inches

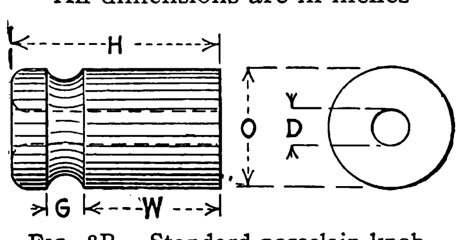


FIG. 8B.—Standard porcelain knob.

Trade number	H Height	O Outside diameter	D Hole diameter	G Width of groove	W Height of wire
0	$2\frac{1}{4}$	3	$1\frac{1}{4}$	1	$\frac{9}{16}$
1	3	$2\frac{1}{2}$	$\frac{7}{16}$	$\frac{3}{4}$	$1\frac{3}{4}$
2	2	2	$\frac{1}{2}$	$\frac{1}{2}$	1
3WG	$1\frac{1}{4}$	2	$\frac{7}{16}$	$\frac{3}{4}$	$\frac{9}{16}$
3	$1\frac{1}{4}$	2	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{3}{4}$
$3\frac{1}{2}$	2	2	$\frac{7}{16}$	$\frac{7}{16}$	1
4	$1\frac{11}{16}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{8}$
Midway	$1\frac{7}{8}$	$1\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	1
$4\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{7}{16}$	1
5	$1\frac{1}{4}$	1	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{11}{16}$
$5\frac{1}{2}$	$1\frac{9}{16}$	1	$\frac{1}{4}$	$\frac{5}{16}$	1
6	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{7}{32}$	$\frac{1}{4}$	$\frac{1}{2}$
7	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{1}{4}$	$\frac{7}{16}$	$\frac{1}{8}$
8	$\frac{15}{16}$	1	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{7}{16}$
9	$1\frac{1}{8}$	$\frac{5}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{4}$
10	$1\frac{3}{4}$	$1\frac{5}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$1\frac{5}{16}$
$10\frac{1}{2}$	$1\frac{7}{8}$	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	1

16E. Tubes for knob and tube work can be obtained in many lengths and sizes, as indicated by Table **16F**. A tube $3\frac{1}{2}$ in. long, $\frac{5}{8}$ in. external diameter and $\frac{5}{16}$ in. internal diameter, is the size most frequently used in ordinary house wiring.

16F. Dimensions of Code Standard Unglazed Porcelain Tubes

(*R. Thomas & Sons Company*)

All dimensions are in inches. An allowance of one sixty-fourth of an inch for variation in manufacturing is permitted, except in the thickness of the wall.

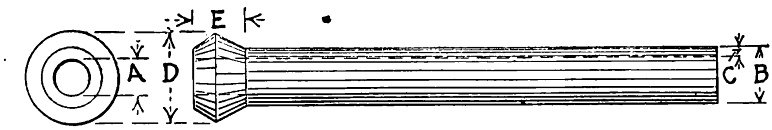


FIG. 8C.—Standard porcelain tube.

A Diameter of hole	B External diameter	C Thickness of wall	D External diameter of head	E Length of head	Greatest length made	Shortest length made
$\frac{5}{16}$	$\frac{9}{16}$	$\frac{1}{8}$	$\frac{13}{16}$	$\frac{1}{2}$	24	$\frac{1}{2}$
$\frac{3}{8}$	$\frac{11}{16}$	$\frac{5}{32}$	$\frac{15}{16}$	$\frac{1}{2}$	24	$\frac{1}{2}$
$\frac{1}{2}$	$\frac{13}{16}$	$\frac{5}{32}$	$1\frac{3}{16}$	$\frac{1}{2}$	24	1
$\frac{5}{8}$	$\frac{15}{16}$	$\frac{5}{32}$	$1\frac{5}{16}$	$\frac{1}{2}$	24	1
$\frac{3}{4}$	$1\frac{3}{16}$	$\frac{7}{32}$	$1\frac{11}{16}$	$\frac{5}{8}$	24	1
1	$1\frac{7}{16}$	$\frac{7}{32}$	$1\frac{15}{16}$	$\frac{5}{8}$	24	$1\frac{1}{2}$
$1\frac{1}{4}$	$1\frac{13}{16}$	$\frac{9}{32}$	$2\frac{5}{16}$	$\frac{5}{8}$	24	$2\frac{1}{2}$
$1\frac{1}{2}$	$2\frac{3}{16}$	$\frac{11}{32}$	$2\frac{11}{16}$	$\frac{3}{4}$	24	$2\frac{1}{2}$
$1\frac{3}{4}$	$2\frac{9}{16}$	$\frac{13}{32}$	$3\frac{1}{16}$	$\frac{3}{4}$	24	$2\frac{1}{2}$
2	$2\frac{15}{16}$	$\frac{15}{32}$	$3\frac{7}{16}$	$\frac{3}{4}$	24	$2\frac{1}{2}$
$2\frac{1}{4}$	$3\frac{5}{16}$	$\frac{17}{32}$	$3\frac{13}{16}$	1	24	$2\frac{1}{2}$
$2\frac{1}{2}$	$3\frac{11}{16}$	$\frac{19}{32}$	$4\frac{3}{16}$	1	24	$2\frac{1}{2}$

16G. Approximate Dimensions of Two- and Three-wire Porcelain Cleats

(*The R. Thomas & Sons Company, East Liverpool, Ohio*)
All dimensions are in inches

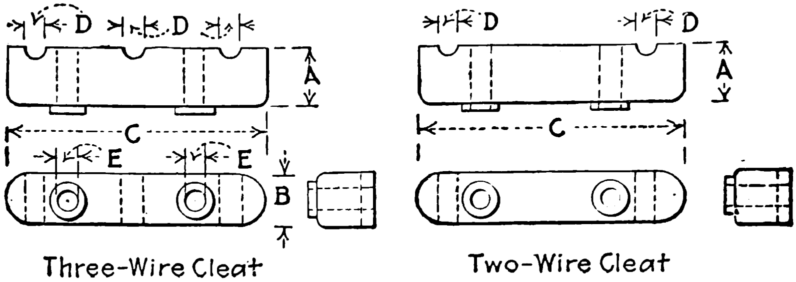


FIG. 8D.—Two- and three-wire porcelain cleats.

Standard No.	No. of wires	For size wires	A Height	B Width	C Length	D Groove	E Diameter screw hole
333	1	18–10	$\frac{1}{2}$	$\frac{1}{2}$	$1\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{16}$
[1] 333½	....	....	$\frac{1}{4}$	$\frac{1}{2}$	$1\frac{3}{16}$	....	$\frac{3}{16}$
334	2	18–10	$1\frac{1}{8}$	$\frac{5}{8}$	$3\frac{3}{8}$	$\frac{3}{16}$	$\frac{7}{32}$
335	2	18– 8	$1\frac{1}{8}$	$\frac{3}{4}$	$3\frac{3}{8}$	$\frac{5}{16}$	$\frac{7}{32}$
336	2	18–10	$1\frac{1}{8}$	$\frac{5}{8}$	$3\frac{3}{8}$	$\frac{3}{16}$	$\frac{7}{32}$
[2] 337	3	....	....	....	....	....	....
350	2	4– 2	$1\frac{1}{2}$	$\frac{3}{4}$	$3\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{16}$

[1] No. 333½ has no groove and of itself could not be used as a cleat. It is simply a flat piece of porcelain to be used in combination with No. 333, the screw holes of the two corresponding.

[2] No. 337 is a three-wire cleat and can be made of the dimensions of Nos. 334, 335 or 336.

16H. B. & D. Porcelain Cleats.

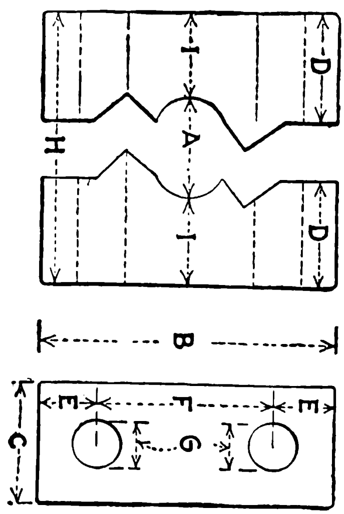


FIG. 8E.—Showing cleats the dimensions of which are given in Table 16I.

161. Dimensions of Regular Style B. & D. Porcelain Cleats

(See Fig. 8E for key to reference letters.)

No.	Std. No.	Size wire R. C. B. & S.	Dimensions A Min in.	A Max. in.	B in.	C in.	D in.	E in.	F in.	G in.	H Min. in.	H Max. in.	Approx. price each
1	328	14 to 16	3/16	3/8	1 3/4	3/4	5/8	5/16	1 1/8	1/4	1 1/4	1 7/16	0.01
1 1/2	329	10 to 2	3/16	7/16	2 1/4	15/16	3/4	15/32	1 5/16	5/16	1 1/2	1 3/4	0.016
2	....	2 to 0	3/8	1/2	2 1/4	1 1/16	13/16	15/32	1 5/16	5/16	1 5/8	1 3/4	0.019
2 1/2	330	0 to 3/0	1/2	5/8	2 11/16	1 3/16	1	17/32	1 5/8	5/16	2	2 1/8	0.024
3	331	3/0 to 200,000 cm.	1/2	3/4	3 1/8	1 1/4	1 3/16	5/8	1 7/8	3/8	2 3/8	2 5/8	0.032
3 1/2	331 1/2	200,000 cm. to 500,000 cm.	3/4	1	3 3/16	1 5/16	1 3/8	5/8	1 15/16	3/8	2 1/4	3	0.049
4	332	500,000 cm. to 1,000,000 cm.	7/8	1 3/8	3 11/16	1 3/8	1 7/16	11/16	2 5/16	3/8	2 7/8	3 3/8	0.065
4 1/2	332 1/2	1,000,000 cm. to 2,000,000 cm.	1 3/8	1 15/16	5 3/8	2	1 15/16	7/8	3 5/8	9/16	3 1/4	4 3/16	0.164

NOTE.—Nos. 1 to 3 inclusive, regular cleats (as tabulated), approved for 300 volts and Nos. 3½ to 4½ regular cleats (as tabulated), approved up to 550 volts. If cleats Nos. 1 to 3 are desired for service above 300 volts "style A" should be specified, in which Dimension I is 1 in. in every case.

16J. Flexible tubing or circular loom (Fig. 8, *F*) finds application in mixed wiring, where short sections of rigid conduit are installed, being used as additional insulation and protection for the entire length of conductor within the rigid conduit. When metal outlet boxes are used, or switch boxes, flexible tubing is required from the last porcelain support and extending into the outlet box. Another application for flexible tubing is in buildings already completed where the wires are fished in between the walls and ceilings. The tubing is used as a covering on such wires separately encased. In concealed knob and tube work it is frequently impracticable to place wires 5 in. apart and 1 in. from the surface wired over as required by the code, and in such cases the wires may be separately encased in flexible tubing. In open wiring where the amount of separation required by the code from the surface wired over cannot be maintained, the wires may also be encased in flexible tubing.

The following is a list of places where flexible tubing is applicable: In open work where wires are exposed nearer each other than $2\frac{1}{2}$ in.; on wires crossing other wires; on wires crossing gas pipes, water pipes, iron beams, wood work, brick or stone; on wires at chandeliers and bracket outlets; on gas pipe back of insulating joints; on wires under the edges of canopies; and at distributing centers or where space is limited and the 5-in. separation required cannot be maintained, each wire must be separately encased in a continuous length of flexible tubing. In many other places flexible tubing is employed as an added protection to wires; as for instance on portable wires around machinery and in show windows, etc., where added protection although not required is often desirable.

Knox in his *Electric Light Wiring* says: The use of flexible tubing is becoming more limited every year and as a separate method of wiring is only approved by certain inspectors. It is used in nonfireproof buildings and is frequently used in conjunction with other methods of wiring, such as knob-and-tube wiring, exposed wiring on insulators, molding work, etc. It is also used at the backs of switchboards to cover conductors where they emerge from conduit, or where the conductors pass through walls, etc. It must be used on the loop system and be continuous from outlet to outlet. It must not be installed in damp places or in any way subjected to moisture (such as being placed in contact with damp mortar, plaster, etc.). Wires should not be drawn into flexible tubing until after the rough work in the building is finished as the tube is not strong mechanically and would not protect the wires from nails, etc. Duplex wires are not permitted in flexible tubing, although single-braided conductors are allowed.

Owing to the fact that flexible tubing is neither moisture-proof nor mechanically strong, it compares unfavorably with metallic conduits. Wiring with it is, however, cheaper than either rigid or flexible conduit wiring.

Flexible tubing should be used only in dry places.

16K. Properties of Flexible Tubing or Loom

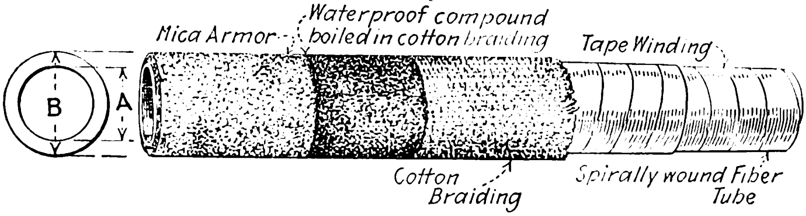


FIG. 8F.—Flexible tubing.

A Inside diam., inches	B Outside diam., inches	Ft. per coil	Largest wire, B. & S. and cir. mils	Weight per 1,000 ft.-lb.
$\frac{1}{4}$	$\frac{17}{32}$	250	No. 14	75 lb.
$\frac{3}{8}$	$\frac{5}{8}$	250	No. 12	110 lb.
$\frac{1}{2}$	$\frac{3}{4}$	200	No. 8	125 lb.
$\frac{5}{8}$	$\frac{7}{8}$	200	No. 4	155 lb.
$\frac{3}{4}$	$1\frac{1}{16}$	150	No. 2	200 lb.
1	$1\frac{3}{8}$	100	No. 00	275 lb.
$1\frac{1}{4}$	$1\frac{11}{16}$	100	200,000	360 lb.
$1\frac{1}{2}$	$2\frac{1}{16}$	100	400,000	400 lb.
$1\frac{3}{4}$	$2\frac{1}{2}$	100	600,000	440 lb
2	$2\frac{3}{4}$	Odd lengths	800,000	600 lb.
$2\frac{1}{4}$	3	Odd lengths	1,100,000	700 lb.
$2\frac{1}{2}$	$3\frac{1}{4}$	Odd lengths	1,300,000	700 lb.

17. **Insulating tape** for the United States Navy Department is purchased under the following specifications:

1. Tape to be classified as follows:

(a) Rubber tape.
(b) Cotton tape.

2. Both classes must meet the following requirements:

(a) Deliveries shall contain full specified weight of tape, exclusive of wrapping and boxes. Net weight only of tape shall be paid for.
(b) All tapes shall be of recent manufacture.
(c) The surface shall be smooth, the body entirely free from holes, the edges straight without selvage and widths even. When held before a strong light there must be no evidence of pin holes.
(d) The wrappings shall be secure and protect the contents fully.

3. The cotton tape must be well saturated and frictioned, but compound shall not be put on in excess. Separation under a pull of 2 lb. per inch width applied to the material when wound from the original in a coil on a $\frac{1}{4}$-in. mandrel under a tension of 10 lb. shall not exceed 8 in. per minute at 75 deg. fahr.

4. When unwinding from the original coil there must be no tendency to leave a thread sticking to the next layer in the case of cotton tape, nor shall the separator show any tendency to stick in the case of rubber tape. Rubber tape, when wrapped to a thickness of $\frac{1}{4}$ in. and heated to 150 deg. fahr. for 20 min., shall fuse into a homogeneous mass.

5. Cotton tape, when exposed in strip to dry heat at 210 deg. fahr. for 16 hr. shall stand the following separation test immediately

after removal from the heat. Test similar to that in paragraph three will be made, except that the pull shall be two ounces per inch width and the separation shall not exceed 3 in. per minute.

6. The weight of the compound applied to the cloth shall be about 0.65 lb. per square yard.

7. To possess the following physical and chemical characteristics:

Width, inches: Rubber, ½, ¾, and 1; cotton, ½, ¾ and 1.

Thickness, inches: Rubber, 0.035, approximately; cotton, 0.015, approximately.

Package, pounds: Rubber, ¼, ½, and 1; cotton, ⅜ to ⅔ (all widths).

Length of tape per pound weight (minimum): Rubber, 27, 18, and 13.5 yards; cotton, 72, 48, and 36 yards.

Para rubber: Rubber, not less than 30 per cent.

Sulphur: Rubber, not more than 3½ per cent. total.

Ash by burning: Rubber, not to exceed 65 per cent.; cotton, not to exceed 45 per cent.

Tensile Strength: Rubber, 400 lb. per square inch at 75 deg. fahr.; cotton, 40 lb. per inch of width.

Dielectric Strength: Rubber, 250 volts per millimeter of thickness (5 minims); cotton, 1,000 volts (5 minims).

Color: Rubber, black; cotton, black.

Layer separation: Rubber, linen or glazed cloth.

Packing: Rubber, oil paper or tinfoil; and in pasteboard box; cotton, tissue paper or tinfoil and in tin box.

Markings of package: Rubber, maker's trade name, width, weight, directions; cotton, maker's trade name, width.

The test for tensile strength of the rubber tape shall be performed on a rubber testing machine, the rate of separation of the jaws which clamp the test piece being 3 in. per minute. The initial distance between the jaws shall be 3 in. The test for tensile strength of the cotton tape shall be conducted with a textile testing machine or by lifting the specified weight.

The dielectric strength tests to be conducted as follows: The test piece to be placed between two electrodes consisting of two brass balls, each 2 cm. in diameter, and the specified alternating potential having an effective value, at a frequency of 60 cycles, shall be continuously applied for 5 min. and no break-down shall result. The electrodes must be brought close together so that the tape will just move between them.

17A. Rosettes may be either fused or unfused. Fused rosettes are seldom used now. The usual practice is to connect 16 sockets to a branch circuit, through fuseless rosettes, so that the total wattage of the lamps will not exceed 660. Sockets are usually considered as requiring not less than 40 watts each. The branch circuit can then be properly fused at the point where it connects to the main circuit. Fused rosettes are used, with the underwriters' approval only for open work. Link-fused rosettes can be used for voltages not exceeding 125 and enclosed fused rosettes for voltages not exceeding 250. Where rosettes are fused 30 or 40 lamps may be connected to one branch circuit.

The rosette fuse must not exceed 3 amp. capacity and the fuse protecting the branch must not exceed 25 amp. capacity. It is not now considered good practice to load any incandescent lamp circuit to more than 660 watts. If there are too many lamps on one fuse, its blowing will render too great an area dark.

18. Insulating socket bushings must be used where a cord enters a socket to protect it against abrasion and grounding against the shell. The most popular bushings are of hard rubber or of a compound resembling it. Patented bushings which automatically grip the cord by a wedging action can be purchased.

19. **Sockets** made with a $\frac{1}{8}$-in. or a $\frac{3}{8}$-in. pipe thread. The so-called $\frac{1}{8}$-in. sockets are used only on fixtures. The $\frac{3}{8}$-in. sockets can be used with reinforced lamp cord. In connecting a cord to a socket, the cord should always have a knot (Fig. 9) tied in it that will lie within the socket to insure against its pulling out and to take the strain from the binding screw.

20. **Key sockets should not be used** in places where they are in an atmosphere filled with an inflammable dust. Weather-proof or keyless sockets should be installed in such places.

21. **Brass-shell or key sockets should never be used out of doors or in damp places.** Sometimes, even in bath-rooms, moisture will get into the shell and ground a socket. Occasionally the water comes from the hand of a person that has just washed and turns the key before his hand is dry. The water enters through the slot in the shell. A keyless or a pull-chain socket should be installed in bath-rooms.

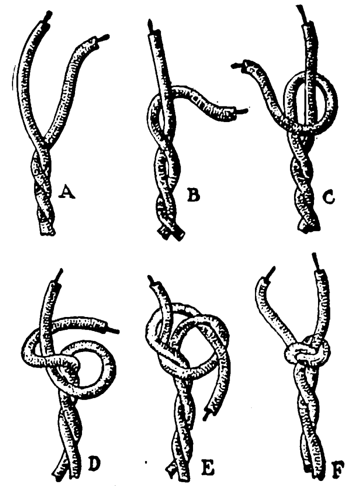


FIG. 9.—Method of tying supporting knot in flexible cord. (See Par. 9 for description.)

22. **Weather-proof sockets** are used out of doors and in damp places as suggested in **95.**

23. **Brief of Underwriters' Rules Covering Cut-outs** (*Factory Mutual Rules*).—Link fuses are not suitable for general use about a factory and will not be approved unless mounted on slate or marble bases made to conform to the specifications given in the Code and enclosed in dust-tight, fire proofed cabinets. (See Fig. 23.) The ordinary porcelain link-fuse cut-outs are not permissible. Approved plug and cartridge fuses may be used almost anywhere in the ordinary manufacturing plant without the enclosing cabinet, such cabinets being necessary only in specially hazardous places, or where persons would be liable to come in contact with the bare live parts. These fuses of the enclosed type are strongly recommended for general use.

In 1903 the enclosed fuse was standardized by a special committee of the underwriters in consultation with the fuse manufacturers. (See specifications in **25.**) This was found necessary in order to secure an interchangeable fuse for any given capacity regardless of the make. This feature had previously been sadly lacking, and the result had been great inconvenience or the use of dangerous substitutes, such as fuse wire, wire nails, etc. The great advantages of an interchangeable fuse are evident.

24. **Relative cost of fuses** of capacities up to 25 amp. is given in Knox's *Electric Light Wiring* as follows: Open-link fuse with copper terminals, $\frac{3}{4}$ cent each; Edison fuse plug, 5 cents each; Edison fuse plug casing with cartridge fuse complete, 15 cents each; cartridge fuse, 8 cents each. These costs are approximate.

25. Dimensions of National Electrical Code Standard Enclosed Fuses

(0 to 60 Amperes)
I Cartridge Fuse-Ferrule Contact

(61 to 600 Amperes)
II Cartridge Fuse-Knife Blade Contact

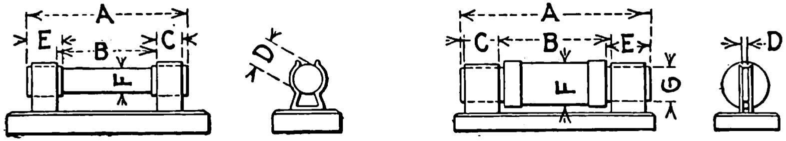


FIG. 10.—National electrical code standard fuses and holders.

Voltage	Rated capacity, amperes		A Length over terminals, inches	B Distance between contact clips, inches	C Width of contact clips, inches	D Diameter of ferrules or thickness of terminal blades, inches	E Min. length of ferrules or of terminal blades outside of tube, inches	F Diameter of tube, inches	G Width of terminal blades, inches		Rated capacity, amperes
0–250	0–30	Form 1	2	1	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{1}{2}$		Form 1	0–30
	31–60		3	$1\frac{1}{4}$	$\frac{5}{8}$	$\frac{13}{16}$	$\frac{5}{8}$	$\frac{3}{4}$			31–60
	61–100	Form 2	$5\frac{7}{8}$	4	$\frac{7}{8}$	$\frac{1}{8}$	1	1	$\frac{3}{4}$	Form 2	61–100
	101–200		$7\frac{1}{8}$	$4\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{1}{8}$		101–200
	201–400		$8\frac{5}{8}$	5	$1\frac{3}{4}$	$\frac{1}{4}$	$1\frac{7}{8}$	2	$1\frac{5}{8}$		201–400
	401–600		$10\frac{3}{8}$	6	$2\frac{1}{8}$	$\frac{1}{4}$	$2\frac{1}{4}$	$2\frac{1}{2}$	2		401–600
251–600	0–30	Form 1	5	4	$\frac{1}{2}$	$\frac{13}{16}$	$\frac{1}{2}$	$\frac{3}{4}$		Form 1	0–30
	31–60		$5\frac{1}{2}$	$4\frac{1}{2}$	$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{5}{8}$	1			31–60
	61–100	Form 2	$7\frac{7}{8}$	6	$\frac{7}{8}$	$\frac{1}{8}$	1	$1\frac{1}{4}$	$\frac{3}{4}$	Form 2	61–100
	101–200		$9\frac{5}{8}$	7	$1\frac{1}{4}$	$\frac{3}{16}$	$1\frac{3}{8}$	$1\frac{3}{4}$	$1\frac{1}{8}$		101–200
	201–400		$11\frac{5}{8}$	8	$1\frac{3}{4}$	$\frac{1}{4}$	$1\frac{7}{8}$	$2\frac{1}{2}$	$1\frac{5}{8}$		201–400

26. **A cartridge fuse** consists of a tube of vulcanized fiber, paper or some similar material (Fig. 11) within which the fuse is mounted. The fuse terminals are connected with contact pieces at the ends of the tube. An insulating, porous powder resembling chalk surrounds the fuse and fills or nearly fills the tube. When the fuse blows the powdered material disrupts the arc. Sometimes the fuse is surrounded by a small air chamber as shown in the illustration.

The formation of an arc is prevented in a cartridge fuse, therefore fuses of this type are more reliable than those of any other.

27. **National Code Standard Ferrule Contact Cut-out vs. Edison Plug Cut-out.**—The following objections have been raised against the code standard fuse-and-holder combination, for currents of less than 60 amp., which is illustrated in Fig. 10.

1. The fuses are difficult to remove with the fingers. Tools are required in some cases for their removal and the tools sometimes cause short-circuits.
2. The spring clips on the cut-outs are sometimes bent and broken off.
3. Frequently the contact between the fuse ferrules and the spring clips is bad due to soft metal in the clips or bending by unskilled persons.
4. The ferrules of the 0–30 amp. fuse are so close together that a shock is likely to be received when a fuse is being taken out or removed, when the workman is standing on grounded conducting material.

The combination of a National Electrical Code standard fuse (Fig. 12, *I*) enclosed in a porcelain Edison plug fuse casing (Fig. 12, *II*) and held in an Edison plug cut-out (*III*) is believed by many practical men to be much superior to the combination illustrated in Fig. 10.

The Edison plug arrangement, if it has any of the four disadvantageous features tabulated above, certainly has them to a lesser ex-

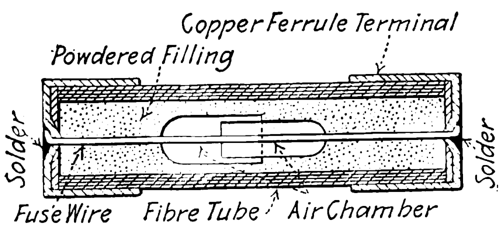


FIG. 11.—Cartridge-type enclosed fuse.

tent than does the spring-clip holder and ferrule fuse arrangement. Edison plug cut-outs are not approved by the underwriters for pressures exceeding 125 volts or currents exceeding 30 amp.

An approved Edison plug cut-out and a fuse-plug casing of the 0–30 amp. size are made by the Bryant Electric Company for 250 volts. The threads of the cut-out socket and those of the casing are left-hand instead of the usual right-hand. Therefore fuse plugs designed for 125-volt service (and which have a right-hand thread) cannot be used in the 250-volt cut-outs.

28. Approximate Cost of Enclosed Fuses in Place (*Nelson S. Thompson, Electrical World*, Sept. 9, 1911).—5 to 65 amp., $0.10

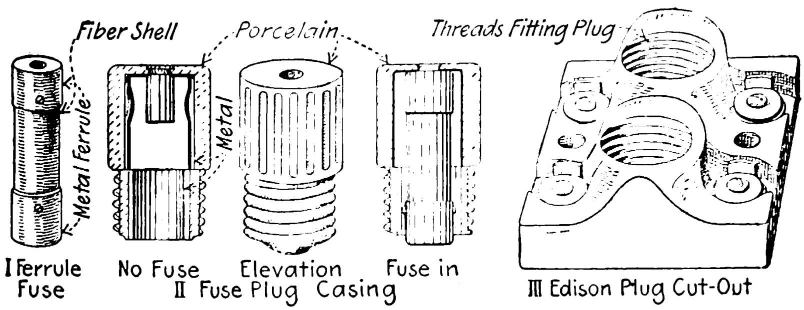


FIG. 12.—Edison plug cut-out and Edison fuse plug casing.

each; 65 to 100 amp., $0.25 each; 110 to 200 amp., $0.50 each; 225 to 400 amp., $0.90 each; 450 to 600 amp., $1.30 each.

29. Open-link fuses (Fig. 13) have the disadvantage of disrupting violently when short-circuited and may burn a person that is near. They blacken the panel that supports them. They are permitted by the Underwriters only when supported on slate bases and enclosed in iron cabinets. When so arranged they will give good satisfaction in industrial plant service where they are handled by journeyman electricians.

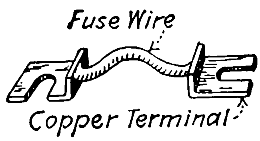


FIG. 13.—Link fuse.

30. Melting Points of Commercial Fuse Wire

From Knox's *Electric Light Wiring*. Table by Mr. Bathurst

The following values are approximate as the fusing point of metals depends on the proportion and kind of alloys used, kind and form of terminal, length of fuse and on other things.

Fusing current in amperes	Diameter in thousandths of an inch	Nearest B. & S. gage
1.7	0.010	30
4.9	0.020	24
9.0	0.030	20
11.3	0.035	19
13.3	0.040	18
19.8	0.050	16
25.4	0.060	14
32.0	0.070	13
39.1	0.080	12
54.1	0.100	10
63.1	0.110	9
81.1	0.130	8
90.6	0.140	7
100.5	0.150	7
110.7	0.160	6
132.1	0.180	5
154.7	0.200	4

31. Diameters of Wires of Various Materials That will be Fused by a Current of a Given Strength

Knox's *Electric Light Wiring.* Derived from tables of W. H. Preece

Current in amp.	Copper		Aluminum		German silver		Iron	
	Diam. in inches	Nearest B. & S. gage	Diam. in inches	Nearest B. & S. gage	Diam. in inches	Nearest B. & S. gage	Diam. in inches	Nearest B. & S. gage
1	0.0021	43	0.0026	41	0.0033	39	0.0047	37
2	0.0034	39	0.0041	38	0.0053	35	0.0074	33
3	0.0044	37	0.0054	35	0.0069	33	0.0097	30
4	0.0053	35	0.0065	34	0.0084	31	0.0117	29
5	**0.0062**	**34**	**0.0076**	**32**	**0.0097**	**30**	**0.0136**	**27**
10	0.0098	30	0.0120	28	0.0154	26	0.0216	24
15	0.0129	28	0.0158	26	0.0202	24	0.0283	21
20	0.0156	26	0.0191	24	0.0245	22	0.0343	19
25	0.0181	25	0.0222	23	0.0284	21	0.0398	18
30	**0.0205**	**24**	**0.250**	**22**	**0.0320**	**20**	**0.0450**	**17**
35	0.0227	23	0.0277	21	0.0356	19	0.0498	16
40	0.0248	22	0.0303	20	0.0388	18	0.0545	15
45	0.0268	21	0.0328	20	0.0420	18	0.0589	15
50	0.0288	21	0.0352	19	0.0450	17	0.0632	14
60	**0.0325**	**20**	**0.0397**	**18**	**0.0509**	**16**	**0.0714**	**13**
70	0.0360	19	0.0440	17	0.0564	15	0.0791	12
80	0.0394	18	0.0481	16	0.0616	14	0.0864	12
90	0.0426	18	0.0520	16	0.0667	14	0.0935	11
100	0.0457	17	0.0558	15	0.0715	13	0.1003	10
120	**0.0516**	**16**	**0.0630**	**14**	**0.0808**	**12**	**0.1133**	**9**
140	0.0572	15	0.0698	14	0.0895	11	0.1255	8
160	0.0625	14	0.0763	13	0.0978	10	0.1372	7
180	0.0676	14	0.0826	12	0.1058	10	0.1484	7
200	0.0725	13	0.0886	11	0.1135	9	0.1592	6
225	**0.0784**	**12**	**0.0958**	**10**	**0.1228**	**8**	**0.1722**	**5**
250	0.0841	12	0.1028	10	0.1317	8	0.1848	5
275	0.0897	11	0.1095	9	0.1404	7	0.1969	4
300	0.0950	11	0.1161	9	0.1487	7	0.2086	4

32. Switches may be classified thus: (1) Surface switches, arranged for mounting on the surface of a wall, which may be of either the open knife-blade or of the enclosed snap-switch types. (2) Flush switches arranged for mounting in a wall or partition with their face plates and operating buttons practically flush with the surface of the wall. (3) Canopy switches which are mounted in wall bracket, electrolier or portable lamp canopies. (4) Pendent switches arranged to hang from a two-conductor cord and open and close the circuit of the cord.

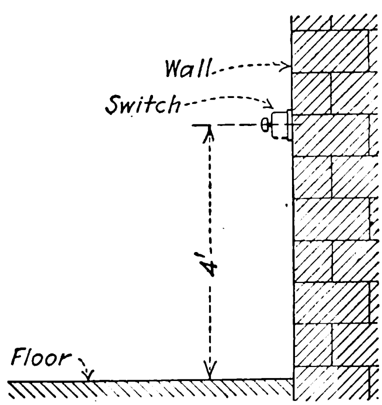


FIG. 14.—Location of wall switch.

33. Copper fuses (Fig. 15) stamped from sheet copper are used for the protection of underground and aerial circuits. They have the disadvantage of becoming very hot before they rupture. At 75 per cent. of their fusing capacities they often become so

hot as to heat terminals or switches to which they are connected to undesirably high temperatures. Copper fuses should always be enclosed in iron boxes. The General Electric Company marks its copper fuses with the current that they will carry without undue heating and recommends them for the protection of underground circuits against dead short-circuits only. Many thousand are in use in this service and for it give excellent satisfaction.

34. Data on Dimensions of Copper Fuses

(From *Electric Light Wiring*—Knox)

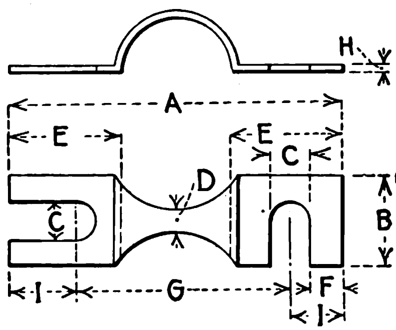


FIG. 15.—Stamped copper fuse.

Amperes	A	B	C	D	E	F	G	I	H
25	1 15/16	7/16	3/16	1/16	17/32	1/8	1 1/2	7/32	0.0071
50	2 1/4	5/8	1/4	1/8	11/16	3/16	1 5/8	5/16	0.0071
75	2 5/8	3/4	5/16	3/32	7/8	7/32	1 7/8	3/8	0.0126
100	3 1/8	7/8	5/16	1/8	1	9/32	2 1/4	7/16	0.0126
150	4 1/8	1	3/8	3/16	1 1/8	5/16	3 1/8	1/2	0.0126
200	4 1/4	1	7/16	1/8	1 3/16	9/32	3 1/4	1/2	0.025
250	4 1/4	1	7/16	5/32	1 3/16	9/32	3 1/4	1/2	0.025
300	4 5/8	1 1/8	7/16	7/32	1 3/8	11/32	3 1/2	9/16	0.025
350	4 5/8	1 1/8	7/16	1/4	1 3/8	11/32	3 1/2	9/16	0.025
400	4 3/4	1 1/4	1/2	9/32	1 7/16	3/8	3 1/2	5/8	0.025
450	4 3/4	1 1/4	1/2	5/16	1 7/16	3/8	3 1/2	5/8	0.025
500	5 1/8	1 3/8	1/2	11/32	1 5/8	7/16	3 3/4	11/16	0.025
600	5 1/4	1 1/2	9/16	3/16	1 11/16	15/32	3 3/4	3/4	0.051
700	5 1/4	1 1/2	9/16	7/32	1 11/16	15/32	3 3/4	3/4	0.051
800	5 1/2	1 3/4	9/16	1/4	1 13/16	19/32	3 3/4	7/8	0.051
900	5 1/2	1 3/4	9/16	5/16	1 13/16	19/32	3 3/4	7/8	0.051
1,000	5 1/2	1 3/4	9/16	11/32	1 13/16	19/32	3 3/4	7/8	0.051
1,100	6 1/2	2 1/4	9/16	3/8	2 5/16	27/32	4 1/4	1 1/8	0.051
1,200	6 1/2	2 1/4	9/16	13/32	2 5/16	27/32	4 1/4	1 1/8	0.051
1,500	7 1/2	2 3/4	9/16	1/2	2 13/16	1 3/32	4 3/4	1 3/8	0.051

36. Switches should be located 4 ft. from the floor (Fig. 14) if they are to control lighting circuits. This is the practice recommended by The American Institute of Architects. Sometimes the character of the wood work or decorations makes it necessary to depart from this standard. Switches controlling the lights in a

room should be located at the entrance to it and not behind the door. Consult the plans and find which way the doors open. Cellar lamp switches should be at the head of the stairs. Hall lamp switches should be near the door into the hall. In first class work three- and four-way switches should be used so the hall lights can be controlled from any floor.

37. Cost of Knife Switches in Place

(*Nelson S. Thompson, Electrical World*, Sept. 9, 1911)

The values are for 250-volt, single-break switches with extension for fuses, polished and without bases, but mounted on panels.

Rating, amperes	Double-pole	Triple-pole
30	$ 1.80	$ 2.30
50	3.05	4.35
100	4.65	6.75
200	7.45	10.95
300	10.45	15.20
400	13.00	19.55
500	18.10	27.00
600	23.10	34.45
800	27.95	41.80
1,000	53.35	63.65
1,200	67.25	87.40

The cost of mounting an unmounted switch not including the drilling of the tablet board is $1.00 per switch.

38. Knife switches (*Power*, April 23, 1912) made by reputable manufacturers are constructed in accordance with National Electrical Code requirements. This pretty effectively protects the buyer, but any switch should be carefully inspected before it is purchased.

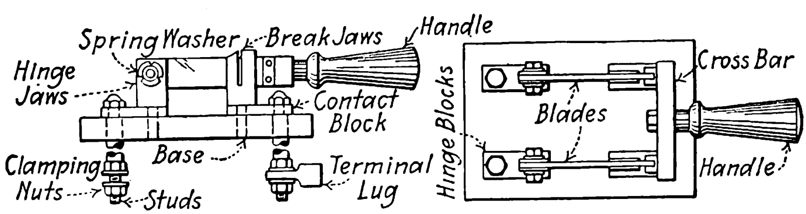


FIG. 16.—Names of knife blade switch parts.

Fig. 16 gives the names of knife switch parts. The contact between the break-jaws and the blade should be carefully inspected, as it is at this point that knife switches are most apt to give trouble by overheating. The contact between the hinge-jaws and the blade seldom limits the capacity of a switch, because it is under pressure from the hinge bolt and the spring washers. The capacity of a switch is determined by its temperature rise. The Code specifies a maximum rise in any part of 50 deg. fahr. at full-load.

39. To make a contact between switch blade and jaws considerable skill is required. After a switch is assembled, the jaws

are first bent into correct position either by hand or by driving a block of wood against the distorted portion with a hammer. Then they are "ground in" with vaseline and fine (FF) pumice stone. Often the "fit" of a switch is reasonably good at the start, and merely working the blade in and out of the jaws by hand will grind them in. Before the grinding process is started, the portion of the blade that wipes the jaws should be daubed with the vaseline and pumice stone compound. The abrasive not only "grinds in the fit" but wears off the lacquer, which, if it remained, might be the cause of a bad contact. The surplus compound should be removed with a rag.

40. A test for good blade contact can be made by trying to insert a "feeler," which is a leaf of very thin steel, mica or paper, between the jaws and blade at the corners and sides. About 0.001 in. to 0.004 in. is about the right thickness for a "feeler." An excellent feeler can be made by hammering down to a knife edge, the edges of a strip of very thin metal possibly 4 in. long and $\frac{3}{4}$ in. wide. If the feeler slips in at any point, it is evident that the "fit" is poor at that point and the contact bad. Proper forming of the jaw will correct the difficulty. There have been cases where switches have been made to carry, without excessive temperature rise, currents 50 per cent. greater than their normal ratings, by merely carefully fitting their jaws to their blades.

41. Knife Switch Ratings.—About 1,000 amp. per square inch of copper section and 50 to 75 amp. per square inch of sliding contact surface is usually allowed in designing switches.

A switch that will carry, possibly, 1,000 amp. with a 20 deg. temperature rise, will carry possibly 2,000 amp. with about a 60 deg. rise. The radiation of heat from the switch increases more rapidly than does the rise in temperature, and as the heat generated varies as the square of the current, it is evident that the temperature rise will be somewhat less than proportional to the square of the current.

A switch will break about double the voltage, with a given current with alternating current as with direct current. This is due to the fact that an alternating current decreases to a zero value during each cycle. The Code recognizes this and specifies that "for 100-amp. switches and larger, the spacings for 250 volts, direct current, are also approved for 250 volts alternating current."

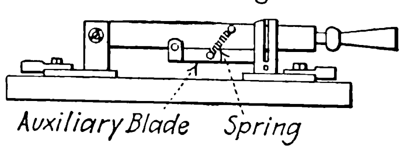


FIG. 17.—A quick-break switch.

The voltage drop from contact-block to hinge-block of a good switch should not exceed about 12 milli-volts with full-load current.

42. Quick-break switches (Fig. 17) have an auxiliary breaking arrangement, actuated by a spring, making it difficult to draw an arc even if the switch is opened slowly. Usually the quick-break attachment is relatively delicate and is apt to get out of order. Where feasible, it is always better to use a switch without a quick-break attachment.

43. Single-throw knife switches should be so mounted that

gravity will tend to open rather than to close them. Double-throw switches can be mounted horizontally, but often when so mounted, it is inconvenient to connect to them, and they do not work in well with many switchboard arrangements; hence they are often mounted vertically and an insulating guard, possibly of wood, is arranged that may be slipped over the jaws on the lower terminals of the switch, to prevent accidental contact. Usually it is best to so connect a switch that the break-jaws will be "alive" and the blades dead when the switch is open. The blades expose more surface and extend further than do the jaws, hence are more liable to accidental contact and short-circuits than are the jaws.

44. **Enclosed snap switches are usually preferable to knife switches,** where it is feasible to use them. Snap switches can be obtained for breaking currents as great as 30 amp. at 250 volts. The unskilled person in opening and closing a knife switch is apt to draw an arc between the contacts, or only partially close the switch, which will pit the metal and ultimately ruin the switch. This condition cannot occur with a good snap switch. Only indicating switches should be installed.

45. **The remote control switch** can often be advantageously used. One manufacturer gives the following as a list of its desirable properties as applied to theater, large building and general wiring:

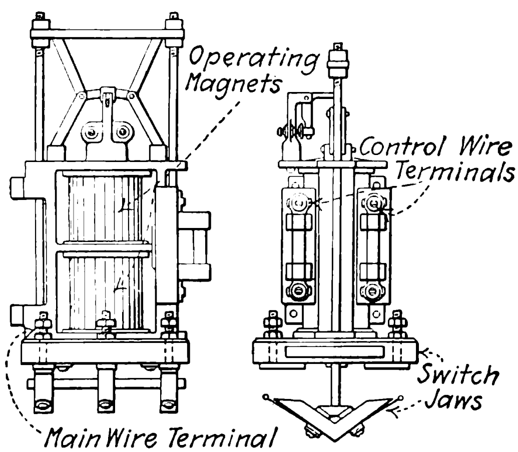


FIG. 18.—A three-pole remote control switch.

1. Simplifies wiring. Main wires can be run in most direct routes, without considering the locations of switch outlets.
2. Often saves money. It takes much less conduit and wire to properly wire some buildings and control the lights with remote control switches than with any other method.
3. Saves annoyance after the building is wired. All lights, or any groups of lights, in a building can be absolutely controlled at all times from any part of the building. Considerable advantages result and great savings are thereby effected in public building and in apartment house light wiring.
4. Enables the owner or custodian of a building to positively cut off the entire current supply of the building by merely pressing a flush push button when leaving the building. This prevents waste of current by lights that have been accidentally left burning, and it eliminates danger of electrical fires.

5. Permits a watchman to control show-window or other store lights without entering the premises.

6. Makes possible the control of current distribution from distant points.

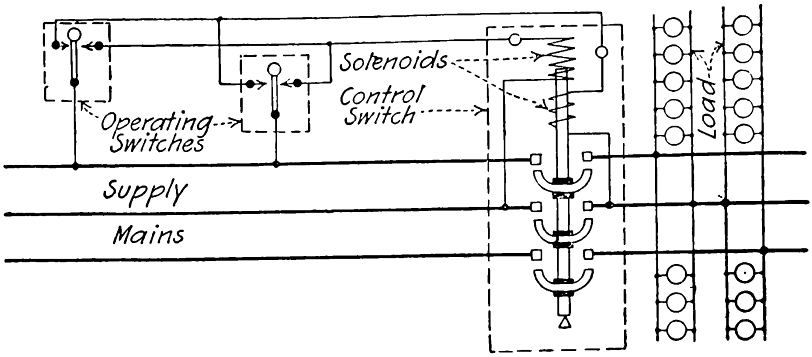


FIG. 19.—Remote control switch circuits.

46. A remote control switch is shown in Fig. 18, its circuits in Fig. 19, and the operating switch in Fig. 20. When the white button of the operating switch is pressed, it permits current to flow through the solenoid that closes the switch. It pulls the jaws together, which closes the main circuit and the jaws are locked in the closed position by the toggle arrangement. The operating current is discontinued by the closing movement. When the black button is pressed, the opening solenoid is energized and the switch opens and severs the operating circuit. Operating switches of several forms are for sale. The principles of all are essentially as described above.

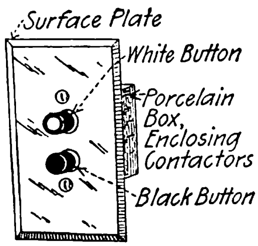


FIG. 20.—Momentary contact switch.

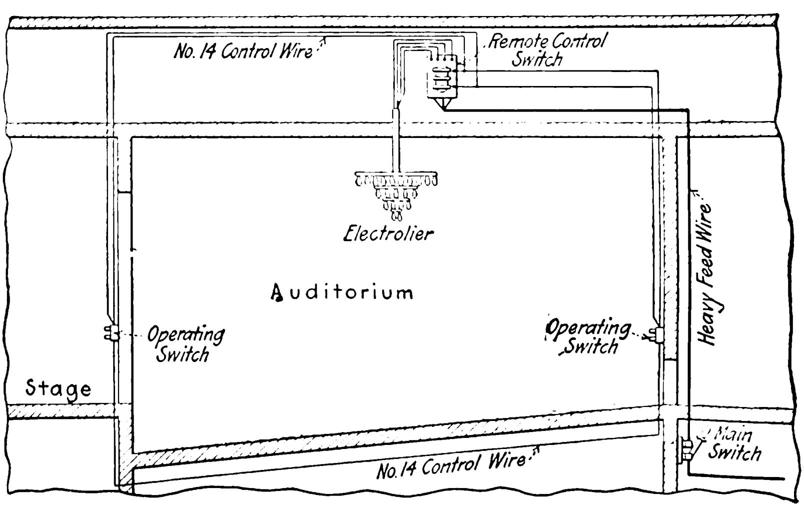


FIG. 21.—Remote control switch installation in a theater.

47. A typical remote control-switch installation is shown in Fig. 21. The main conductors serving the electrolier are carried to the remote control switch near it. Branch lighting circuits from the remote control switch pass to the electrolier. The electrolier is controlled by two conveniently located operating switches —there could be as many more operating switches as desired—but the heavy conductors are not carried to the operating switches. A saving in the cost of conductors thereby results. The operating circuits are of No. 14 wire. Many other applications will suggest themselves wherein circuits may be controlled from various points without its being necessary to carry the main conductors to those points.

48. An iron switch box can be readily made as illustrated in Fig. 22 of sheet metal. It is probably always cheaper to buy a switch box than to make one. When the homemade article must be used, the box is bent from the sheet metal which is indicated

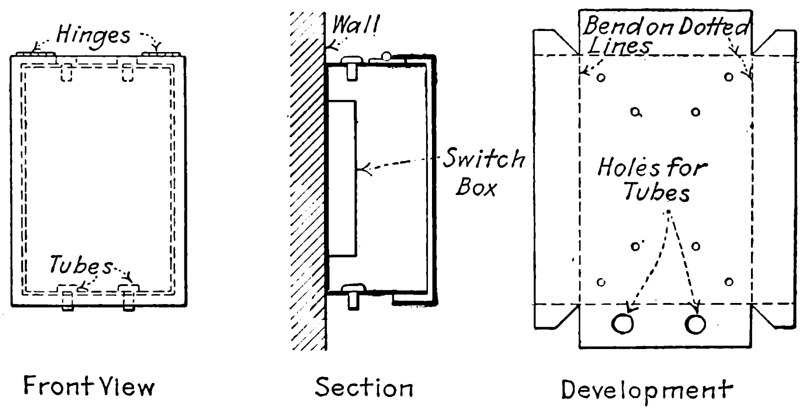


FIG. 22.—A homemade iron switch box.

at *Development*. The cover is formed in the same way. After being bent, the sides are held in position with rivets. Holes are punched for conductor outlets and ordinary tubes are used in them for insulation. The boxes must be painted and be made of metal not less than No. 12 B. & S. gage (approx. $\frac{3}{32}$ in.) thick to comply with Code requirements. The hinges for the door are riveted on. Holes are provided in the back for securing the box to the wall and for supporting the switch within it with stove bolts. (*Electrical World*, March 9, 1912.)

49. Wooden Switch Boxes can be Readily Made (*Electrical World*, May 4, 1912).—Iron ones are preferable and can now be secured from jobbers at costs that compare favorably with or are less than those for homemade wooden boxes. Wooden boxes (Fig. 23) should be of $\frac{7}{8}$-in. well-seasoned wood and lined with $\frac{1}{8}$-in. asbestos, secured in place with tacks and shellac. Sheet iron $\frac{1}{16}$ in. thick or two $\frac{1}{32}$-in. sheets may be used instead of asbestos. The door should close against a rabbet so as to be dust-tight. Where a door is wider than, say, 12 in., it should be paneled with either wood or glass, to insure against distortion due to warp-

ing. A space of 2 in. should be allowed between fuses and the door. A reliable catch should be provided on the door. Porcelain tubes or bushings should be used for insulating where wires enter the box, and should fit the holes snugly. Where necessary, wires should be taped so as to completely fill the holes in the bushings. Bushings reaching just to the inside of the box should be used, as longer ones will be broken. It is recommended that, for factory use, the top of the box be slanted as at III, so that it will not be used as a shelf. A box should be thoroughly filled and painted before it is lined.

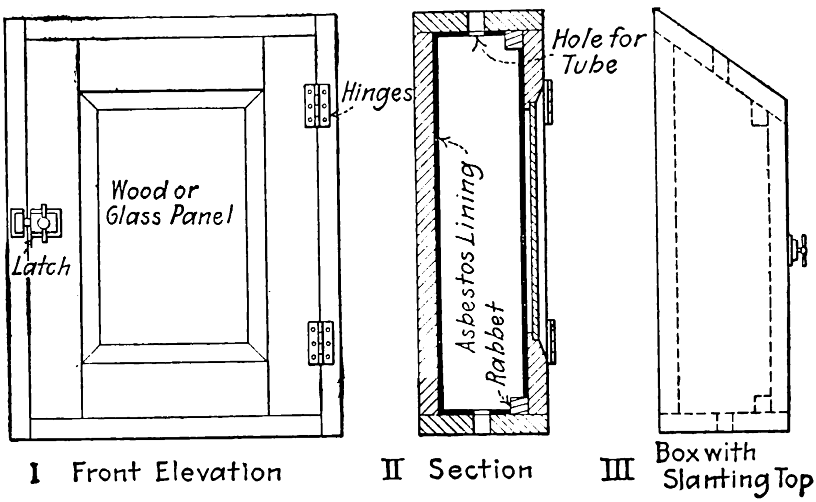


FIG. 23.—A homemade wooden switch box.

Several switches either snap or knife can be mounted in a box like that shown; in fact it might be used as a panel box. A box or cabinet similar to that of Fig. 24 is often convenient, in that it is not necessary to open the door to manipulate the switch. The heavy iron wire handle can be attached to the switch by bending it around the wooden handle, or the wooden handle can be removed and the wire fastened with a nut or a screw eye. If iron conduits, armoured cable or metal moulding terminate in a box, it should be of sheet iron.

50. **Tablet or panel boards** are made in many standard forms and capacities to fit the panel boxes made by their respective manufacturers. Practically all are constructed in accordance with the requirements of the National Electrical Code. One can be reasonably sure that the construction of the tablet boards that have been approved in accordance with the code will be of good construction. Plain black finished slate is probably the best and most serviceable material for a board and a plain lacquered finish on the copper is probably as good as any. In general, plug cutouts are to be preferred and also snap switches are better than knife switches, particularly where they are to be manipulated by persons unskilled electrically. Tablet boards can be assembled

from standard porcelain fittings, as suggested in Fig. 25, held with wood screws.

51. Panel boxes are cabinets arranged to contain cut-outs or cut-outs and switches for protecting and controlling branch circuits where they branch from a main. The miniature switchboard within the box supporting the cut-outs and fuses is called the panel board or the tablet board. It has been found desirable, in so far as possible to group cut-outs in a wiring system and

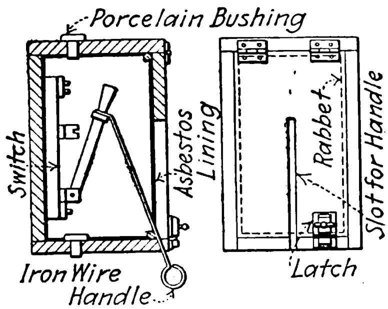


FIG. 24.—An enclosed wooden switch box.

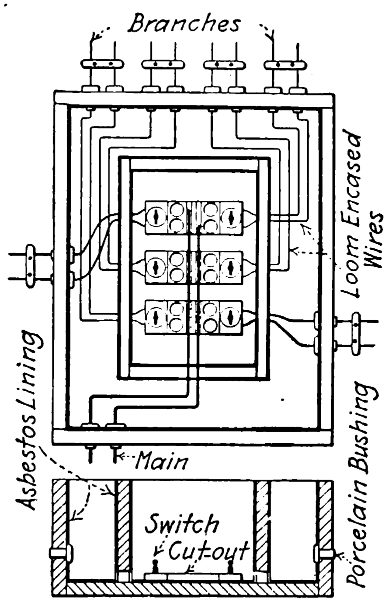


FIG. 25.—A homemade panel box.

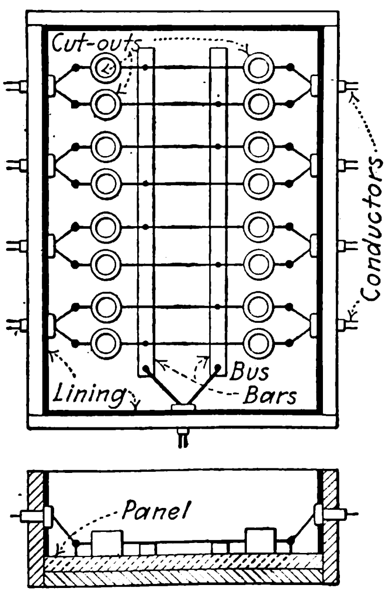


FIG. 26.—A panel box without gutter.

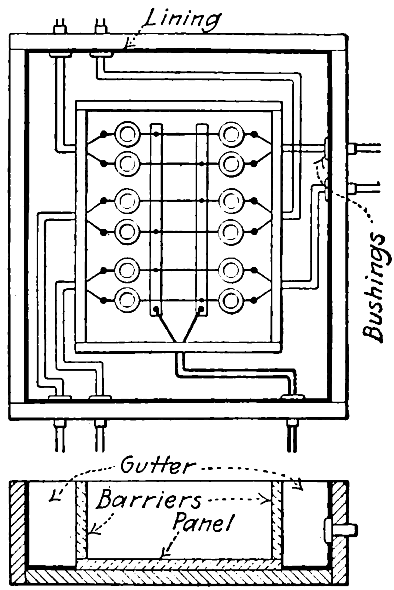


FIG. 27.—Panel box with gutter.

this accounts partially for the popularity of panel boxes. The first panel boxes were made without gutters (Fig. 26) and boxes of this

type are still used to some extent. Their disadvantage is that it is necessary to carry the wires for each branch circuit to a point of the box opposite the proper cut-out. This is often inconvenient and expensive. To obviate this disadvantage panel boxes are now most often made with wiring gutters (Fig. 27). With this arrangement conductors can enter the box at any point on the sides or top and can be carried in the gutter to a point opposite the cut-out.

Panel boxes may be of either the flush or surface type (Fig. 28). The flush type is obviously preferable because it extends but little beyond the surface of the wall. Flush type boxes are always used in first-class residence and office building wiring. Surface type boxes are used principally for factory wiring and for conduit installations in old buildings.

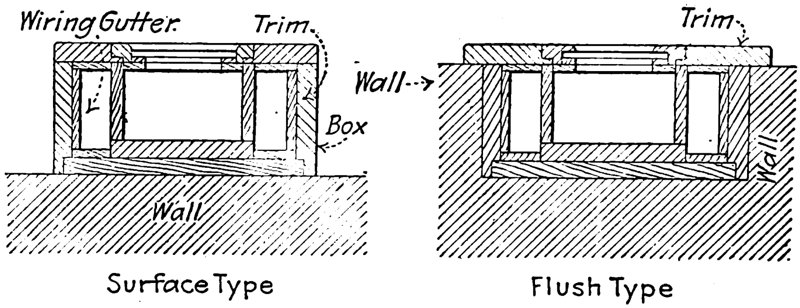


FIG. 28.—Boxes of the surface and flush types.

Panel boxes of sheet steel are suitable for factory work. The barriers in boxes with gutters are usually of slate or marble. The inside of a wooden box must be completely lined with a non-combustible insulating material. Slate or marble $\frac{1}{4}$ in. thick or asbestos board $\frac{1}{8}$ in. thick can be used. Where iron conduit, armoured cable or metal moulding enters the box it should be of painted sheet iron or steel. Boxes should be painted inside and out. An asbestos or steel lining is to be preferred because slate and marble break readily.

The "trim" of a panel box consists of the door and the frame in which it swings. Trims are held to the boxes with screws so they can be readily removed for manipulating wires. The door should close against a rabbet so as to be dust-tight. Glass panels may be used in doors instead of wooden ones and should be at least $\frac{1}{8}$ in. thick. A 2-in. space should be provided between the fuses and the door.

52. **Homemade panel boxes** can be constructed where necessary but it is probable that it is cheaper to buy ready made. See paragraph on *Homemade Switch Boxes* and National Electrical Code rules regarding the construction of cut-out boxes and cabinets. Figs. 23, 25, 26 and 27 illustrate the general construction of boxes. The barrier in a homemade box can be of wood in which case it must be covered on both sides with $\frac{1}{8}$-in. sheet asbestos. For a homemade box standard porcelain cut-out fittings and standard snap switches can be used. They are held with screws to the as-

bestos covered back of the box. Heavy wire can be used for bus-bars. Fig. 25 illustrates the appearance of such a box and the trim can be made as shown in Fig. 28, which illustrates a box with a barrier. One without a barrier would appear like that of Fig. 26.

MISCELLANEOUS WIRING METHODS

53. Service entrances may be made as suggested in Fig. 29 where the wires enter the attic and as in Fig. 30 where the entrance switch and meter are in the basement. The cut-out (fuse-block) should protect the switch. The conductors should be bushed with porcelain tubes where they pass through a wall. Tubes or conduit should be cemented in the wall. The tubes should slant outwardly and downwardly to prevent the entrance of water. A drip loop should be formed in the service wires. The main switch should be arranged to disconnect all of the equipment in the building, except the main cut-out, from the outside wires. Where conduit is used for an entrance two or three rubber-covered wires can be carried in one conduit.

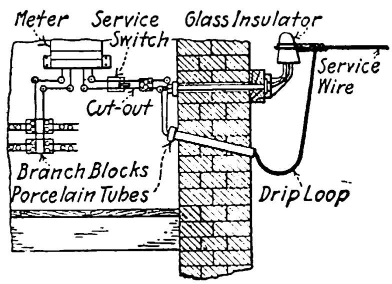


FIG. 29.—Entrance and service switch.

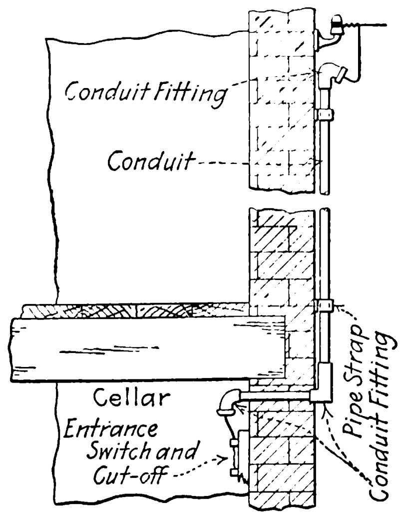


FIG. 30.—Conduit entrance.

54. A typical electric service board is shown in Fig. 31. (*Rules and Regulations of the Commonwealth Edison Co.*).—Service boards are used for installations of considerable capacity. The features of the board shown are: (1) The provision for the removal of links for meter testing and (2) the division of the elevator from the general power, and the lighting from the power. If energy is to be purchased a maximum demand form of contract, space and drilling must be provided for demand meters. Service boards of the general form shown are required by the Commonwealth Edison Company.

55. Brief of Underwriters' Rules Covering the Installation of Switchboards (*Factory Mutual Fire Insurance Co's Wiring Rules*).—Switchboards should be made of slate or marble, supported on metal frames, and should be located well away from combustible materials. They should always be open at the sides, and a space

of at least 12 in. should be left between the floor and the board, and 3 ft., if possible, between the ceiling and the board, in order to lessen the danger of communicating fire to the floor or ceiling, and to prevent the formation of a partially concealed space, very liable to be used for the storage of rubbish, oily waste, etc. The instruments should be neatly arranged and the wiring on the back should be laid out in a careful and workmanlike manner.

It is recommended that all live parts, such as bus-bars and other conductors, be protected against accidental contact as far as practicable by suitable insulation, which shall be "flame-proof" or "slow-burning" and designed to withstand a reasonable amount of abrasion. The chances of accidental short-circuit and arcing

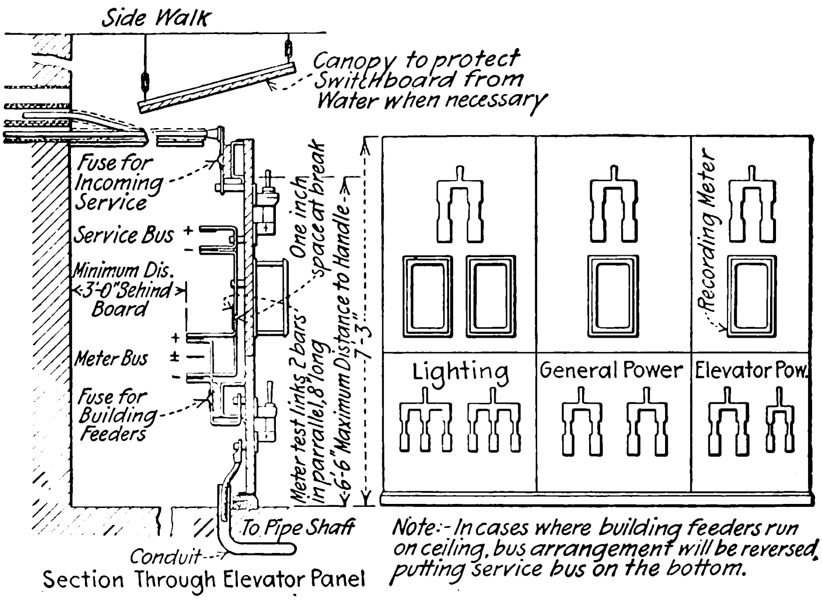


FIG. 31.—Service board.

at these points may thereby be greatly reduced. Insulated cable for bus-bars and connections is excellent for this purpose. However, the conductors could be wrapped or taped if this should be found more convenient, but this method should never be used unless it can be done *well*. Special precautions might also be necessary with either method if applied to high-voltage switchboards.

In addition to the usual measuring instruments and other apparatus, the switchboard should contain reliable devices for testing for grounds.

56. **The following suggestions should be followed in wiring for watt-hour meters** (*Rules and Regulations of the Commonwealth Edison Co., Chicago*): Meter loops should be provided in the mains at an accessible point, and so arranged that the meter may be mounted with ordinary wood screws on the wall. A meter board must be provided of sufficient size to allow the installation of a recording wattmeter and maximum demand meters. Two

demand meters are installed on three-wire mains. Maximum meters will not be installed on installations under 1 kw. Sufficient space must be provided about the meters to allow the removal of the case.

Meter boards should not be erected on a wall which is subject to any considerable vibration, or in places subject to excessive moisture or heat. A pressure wire tap must be provided in all cases where all wires of the circuit are not looped out. On three-wire mains the pressure wire tap must be made on the neutral wire. The general arrangements of meter loops should be such that a meter can be installed without crossing any wires, if possible. If this is impracticable, sufficient flexible tubing should be left on the wires to make possible an installation which will be in accordance with the wiring rules.

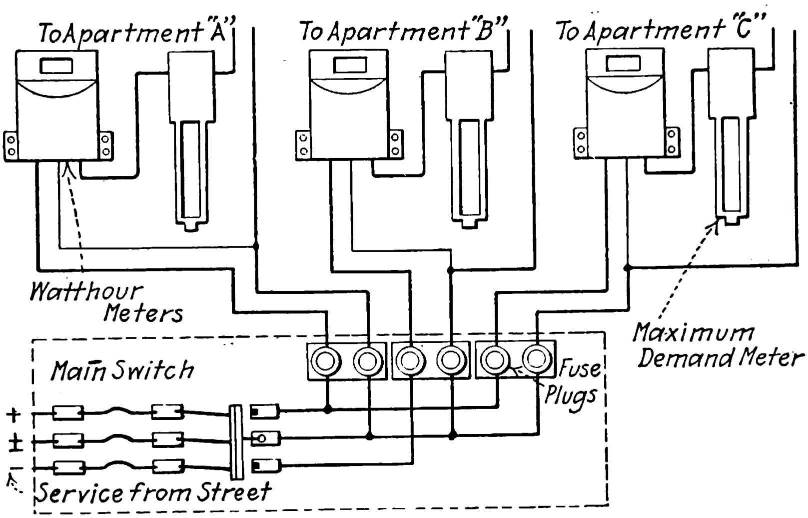


Fig. 32.—Diagram of meter connections and general wiring of meterboard for apartments requiring but one circuit.

Meter loops should not be placed above 7 ft. from the floor, and should be as near the point of entrance of the service as possible. In office buildings meter loops should be located at a central point in meter closets or public corridors, and in apartment buildings in the basement of the building, so that meters may be installed and maintained without annoyance to tenants.

Meter loops must be located relative to fuses so that meters are protected by the fuses. See Figs. 32 and 33. They must never be placed between the service and the service switch. Generally speaking, not more than one meter installation will be provided for the same class of service in any one building.

Meter loops for service to supply temporary lighting or power to new buildings during construction must be located on adjoining premises. No three-wire meters larger than 200 amp. are used. Installations requiring meters of larger capacity will be provided

with two meters, one on each side of the three-wire main; space should be allowed accordingly in arranging meter boards.

57. In connecting Edison plug cut-outs, they should always be so arranged that the screw shells, which extend beyond the porcelain, will not normally be alive. Fig. 34, *I* and *II*, show the right

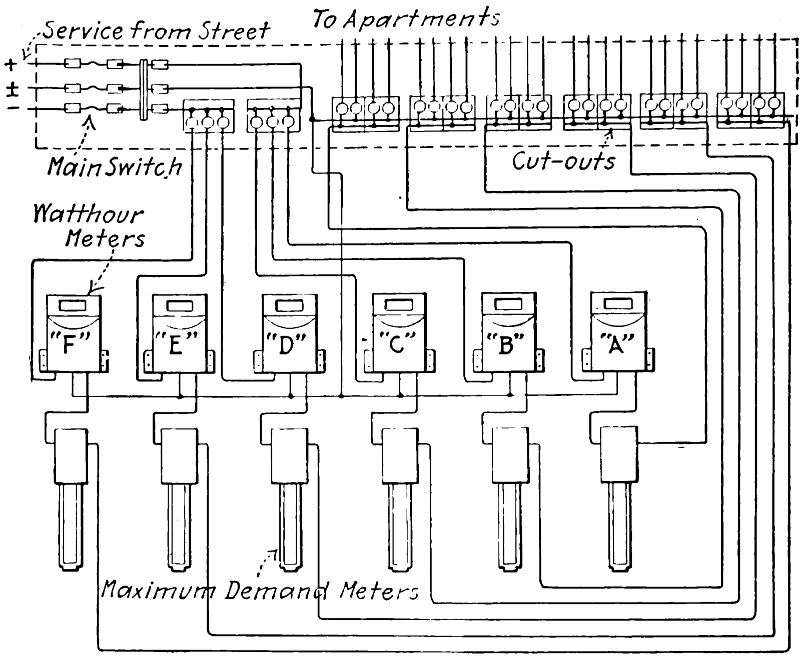


FIG. 33.—Design of meterboard connections for apartments requiring two circuits.

and wrong methods. If connected incorrectly, there is constant danger of short-circuit or shock when men are working about the cut-outs with bare wire ends or tools. Some makes of plug cut-outs are so constructed that the porcelain is higher than the screw shell which is thereby protected. Such cut-outs would be properly

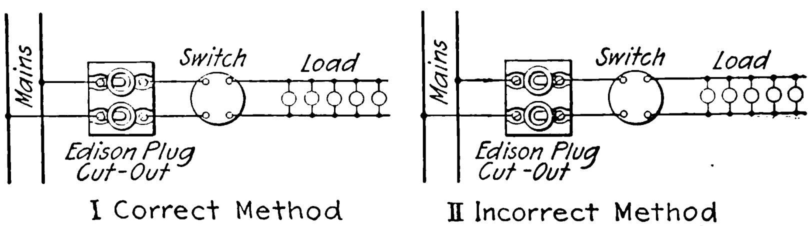


FIG. 34.—Correct and incorrect methods of connecting Edison plug cut-outs.

connected as shown in either *I* or *II* and should therefore be selected where possible. (*Electrical World*, May 4, 1912.)

58. In protecting reinforcing conductors, that is, in protecting conductors that are to operate in parallel with conductors already

installed, the methods illustrated in Fig. 35 may be used. Where small wires are involved and are so located as to be apt to be broken, each reinforcing wire should be protected with its own cut-out, as shown in *I*. Where the wires are heavy and not liable to breakage, both the reinforcing and the reinforced wire can be connected in parallel and can be protected by one fuse, *II*. If the method of *II* were used for the conditions recommended for *I*, one of the wires might break and the remaining one would be

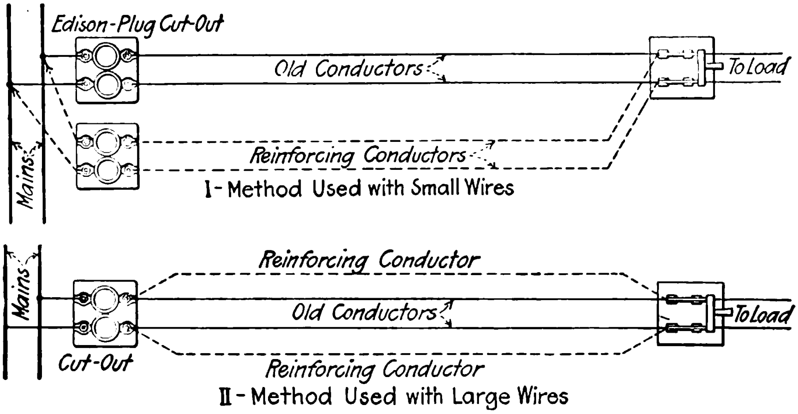


FIG. 35.—Methods of reinforcing conductors.

protected by a fuse too heavy for it. It might, therefore, become overheated and cause a fire. Where at all feasible, the method of *II* should be used, because with that of *I* there is apt to be unproportional division of current between the two conductors, due to differences in contact resistance at the terminals.

59. **A single-pole switch should never be cut in the neutral wire** of a three-wire system because the neutral is usually intentionally grounded and with a switch, cut in the neutral wire, open, the path to ground may be destroyed.

60. **A three-wire to two-wire change-over switch,** or as it is sometimes called, a break-down switch, is connected as in Fig. 36. Such a switch is used when it is necessary to feed a three-wire system from a two-wire or from a three-wire source of energy. Where such a switch is installed the neutral of the three-wire system must have an area equal to the sum of the areas of the two outside wires because when operating from a two-wire source the current in the middle wire will be twice that (assuming the system to be balanced) in either of the outer wires. If arc lamps are used on such a three-wire system they must all be connected between the neutral and a certain one of the outside wires or some special scheme of connection must be adopted. If they are not so connected, polarities will be reversed when the change-over switch is thrown.

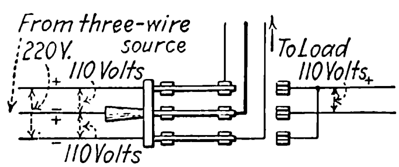


FIG. 36.—Three-wire to two-wire switch.

61. Connections are sometimes reversed in double-pole, snap switches, even by experienced wiremen. Many makes of snap switches "cross-connect" (Fig. 37), that is, the contact bar, when the switch is closed, connects each terminal with the one diagonally opposite. If, through error, the leads are connected as at *II*, a short-circuit may be established through the switch.

62. Single-pole switches are permitted, by the Underwriters, on circuits carrying loads not exceeding 600 watts at pressures not exceeding 300 volts. This gives a maximum permissible current of 3 amp. at 220 volts, or 6 amp. at 110 volts. With these loads, single-pole switches will give good service in residences where the circuits are not apt to be disturbed, but in industrial plants, single-pole switches may give trouble, as described below, and it is good practice to use double-pole switches in such installations where reliability of service is important.

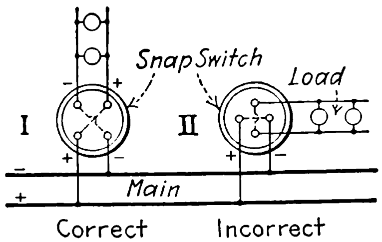


FIG. 37.—Snap switch connections.

63. Single-pole switches may cause trouble because they open but one side of the circuit. For example (Fig. 38 *I*), if one side of a two-wire main happens to be grounded, a ground on the side of opposite polarity, on a branch circuit controlled by a single-pole switch, will form a closed circuit. If the grounds are of sufficiently low resistance, enough current will flow to light the lamps,

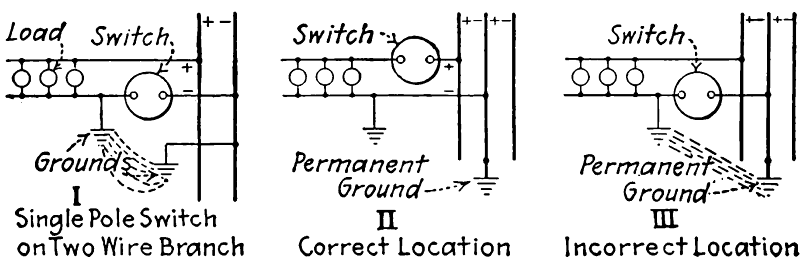


FIG. 38.—Connection of single-pole switch on branch circuits.

even with the switch open. If the resistance of the grounds is high, not enough current will flow to light the lamps. Furthermore, with conditions as shown at *I*, if a wireman accidentally touches a wire of the + side of the branch circuit to any grounded object, such as a gas pipe, a short-circuit would result.

64. Single-pole switches in two-wire branches from three-wire mains should not be inserted in the branch wire connected to the neutral wire of the three-wire system. (See Fig. 38, *II* and *III*.) The neutral of a three-wire system is usually permanently grounded at the central station as well as elsewhere, and with the switches in a neutral branch wire (*III*), trouble is more apt to occur than when the switch is in the other branch wire, as at *II*.

65. Where the switch must be at the opposite end of a room from the entrance the wiring should be arranged as shown at Fig. 39, *II* rather than as at *I*. The method of *I* requires four wires the length of the room while that of *II* requires but three.

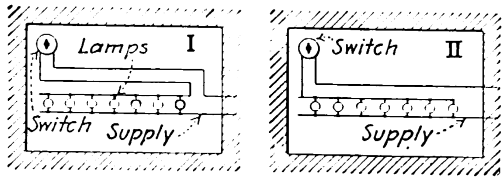


FIG. 39.—Switch at opposite end of room from entrance.

66. Wiring for a switch-controlled lighting circuit, which feeds from another circuit which is also controlled by a switch. Three methods are shown in Fig. 40. With that of *I*, when the main circuit is switched off the branch circuit is extinguished also. With the methods of *II* and *III*, either the main or the branch circuit can be controlled independently but the arrangement of *II* requires four wires the length of the room, while that of *III* requires but three wires.

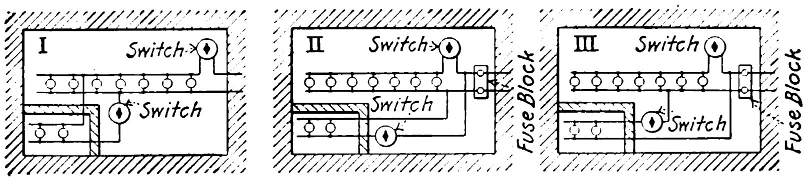


FIG. 40.—Control of lights on sub circuit.

67. Where each half of the lamps in a room must be controlled independently the method of Fig. 41, which permits of such control with minimum wiring, can be used.

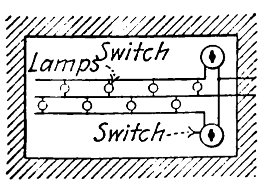


FIG. 41.—Each switch controls half of the lamps.

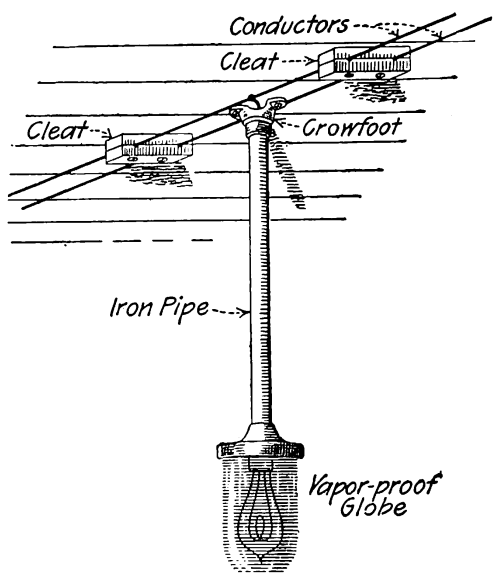


FIG. 42.—Vapor-proof globe on pipe hanger.

68. Sockets in rooms where inflammable gases may exist should be enclosed in a vapor-tight globe (Fig. 42) and supported

on a pipe-hanger, wired with approved rubber-insulated wire soldered directly to the circuit. The upper end of the pipe should be sealed with compound if the room is damp.

69. **In fastening cords in sockets,** some precaution should be taken to prevent stray strands of wire from coming in contact with metal, and thereby causing short-circuits or grounds. This can be accomplished by dipping the bared conductor of the cord in molten solder before it is made up under the binding screw. Strips of tape, about $\frac{1}{4}$ in. wide, torn from wider pieces, are sometimes wound about the braid at the end of bared cord, to prevent

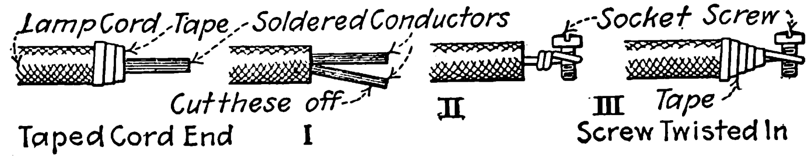


FIG. 43.—Method of connecting flexible cord in socket.

the braid from unraveling. See Fig. 43. A good method of fastening a cord in a socket (Fig. 43, *I*, *II* and *III*), is to cut half of the conductor away, twist the remaining strands into a little cable and then make it up about the screw. Tape should be applied as shown. (*Electrical World*, May 4, 1912.)

70. **Insulating joints** (*Electrical World*, June, 29, 1912) are used to insulate fixtures from grounded parts of a building. The wiring spaces within fixtures are so confined that grounds are very liable to occur in them. If the fixture is insulated from the grounded parts, one ground within it is not liable to do harm. Fig. 44 shows

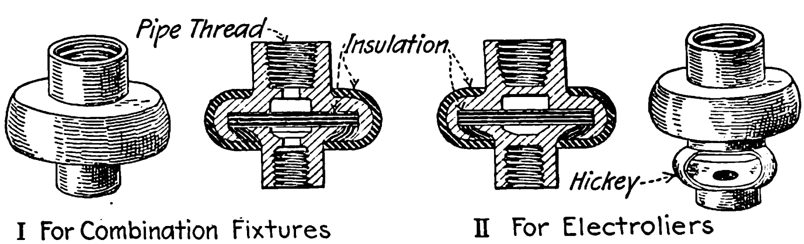


FIG. 44.—Insulating joints.

some insulating joints. That at *I* is used for combination gas and electric fixtures. It has a hole through it to permit the passage of gas. That shown at *II* is for electroliers, and has no hole through it.

71. **In insulating combination fixtures,** the insulating joint should be located as near as feasible to the ceiling, and the wire ends, left after connecting, should never be twisted around the supporting pipe above the joint. (See Fig. 45.) Flexible tubing is required on the wires in knob and tube work and it should extend to below the joint. The Code requires that the pipe above the joint be protected with insulating tubing, which may be either a heavy wrapping of tape or circular loom.

72. Fixtures can be supported in frame buildings by the method of Fig. 46. A wooden strip or cleat should be fastened just above the lath during the construction of the building to take the screws to hold a canopy block. The wooden canopy block supports, with wooden screws, the fixture crow-foot and insulates the canopy

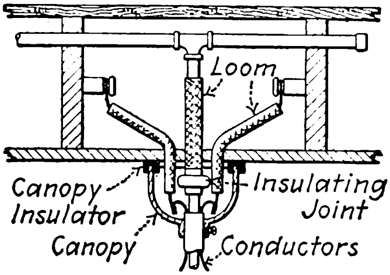


FIG. 45.—Insulating joint for a combination fixture.

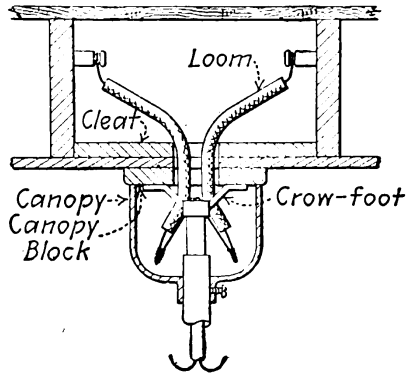


FIG. 46.—Electric fixture support.

from the ceiling. A screw hook turning into a joist (Fig. 47) can be used for sustaining heavy fixtures in frame buildings. A special insulating joint having an eye is screwed on the fixture stem to insulate the fixture from the ceiling or a chandelier loop can be used on a regular insulating joint. In fire-proof buildings, where

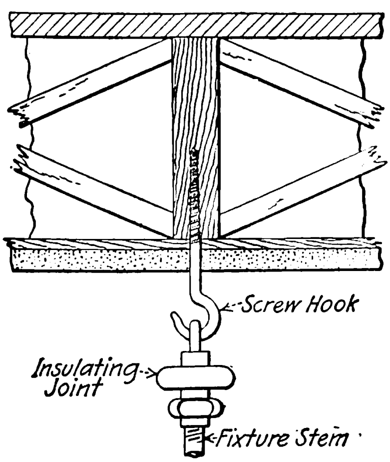


FIG. 47.—Supports for heavy fixtures.

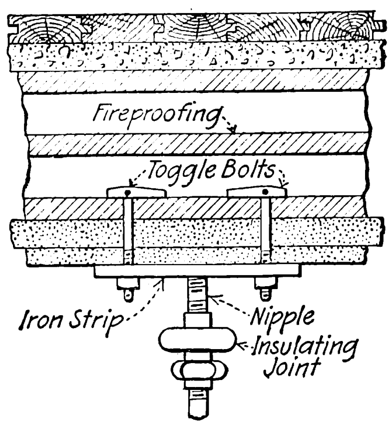


FIG. 48.—Support from a fireproof ceiling.

fixtures must be erected after the building is completed, an iron strap (Fig. 48) held to the surface of the ceiling with a couple of toggle bolts can be utilized for supporting a fixture. A pipe or conduit nipple, turning into a threaded hole in the strap, takes the weight of the fixture.

73. **Fixture canopies can be insulated** from ceilings and walls with commercial canopy insulators, of which there are many forms on the market. Canopies are usually supplied already fitted with insulating rings by the fixture manufacturers. Where canopy insulators must be "home-made," the method of Fig. 49 or that of Fig. 50 may be followed. In Fig. 49 a ring of fiber formed from the sheet material is bent to fit the interior of the canopy, and is held therein with wires or small rivets. The ring should extend about

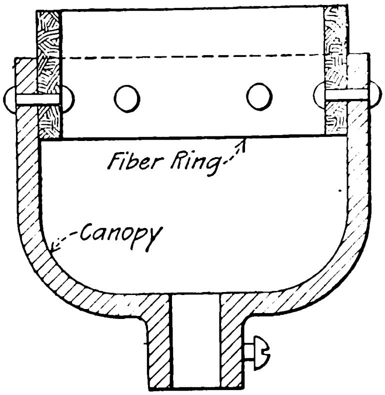


FIG. 49.—Fiber-ring insulator.

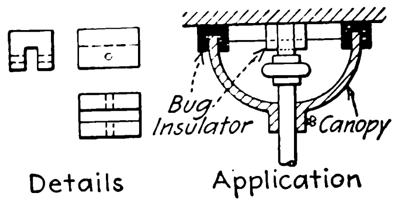


FIG. 50.—Bug insulator.

$\frac{3}{8}$ in. above the top edge of the canopy. Another canopy insulator, sometimes termed a "bug" insulator, can be sawed from block fiber, as shown in Fig. 50. The upper edge of the canopy rests in a slot sawed in the "bug." At least three such insulators should be used for every canopy. A small nail or wire driven through a

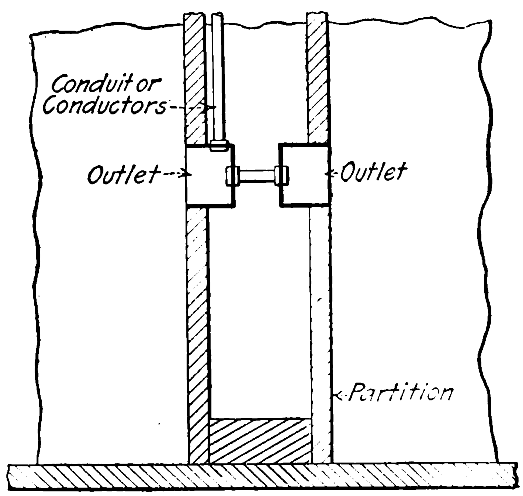


FIG. 51.—Outlets opposite one another in a partition.

hole in the insulator, and one in the canopy, holds each "bug" in position. This method of Fig. 50 is not approved by the Underwriters, whose rules require that the entire edge of the canopy be insulated.

74. **Wall or partition outlets in adjoining rooms should always be located opposite one another** (Fig. 51).—In general, this applies

to both switch and fixture outlets. The reason is that in nearly every case a considerable amount of wiring can be saved by following this construction. This applies to conduit as well as to knob and tube wiring.

75. A method of making up a ground wire where it is to be connected to a pipe and no ground clamp is available. A length, possibly 3 ft., of the ground conductor is "skinned" and carefully scraped or cleaned with fine sandpaper. The pipe on which the connection is to be made is filed bright and clean for a distance of several inches and "tinned" if the connection is to be soldered. Then the bared end of the conductor is arranged, on the brightened portion of the ground pipe, as indicated in Fig. 52, *I*. The free end of the wire (c, c, c) is then served around the pipe as suggested at *II*, and the free end, c, of the wire is passed through the loop B

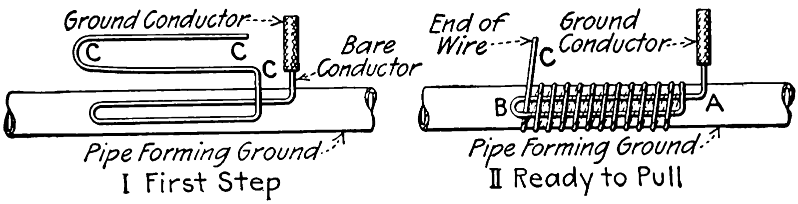


FIG. 52.—Making-up a ground wire.

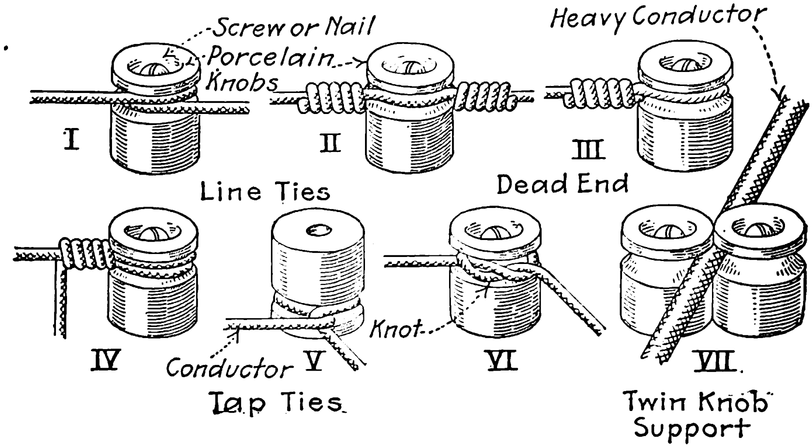
The end A is then pulled. This draws the loop B and the end c up tightly against the other turns and effectively prevents the wrapping from unwinding.

In an actual connection the turns on the pipe are wound closely together. They are shown separated better to illustrate the method. The connection can be soldered with a blow torch and wire solder using a paste flux or by pouring molten solder over the connection until it is hot enough for the solder to adhere.

Where soldering is not feasible the connection can be wrapped with a couple of layers of tin-foil and then with several layers of friction tape. These layers exclude moisture and prevent oxidization. One of the large telephone companies has used the tin-foil and tape method on many hundreds of ground connections for telephone subscribers' stations with excellent results. The tin-foil and tape should extend along the pipe for several inches on each side of the connection and should be wrapped firmly so that they will form a moisture-proof jacket.

76. Knobs and Methods of Supporting Conductors on Them.—Knobs for supporting conductors in interior work are of porcelain. Split knobs or cleats should be used for supporting conductors smaller than No. 8 B. & S. gage. Some methods of securing wires to knobs are shown in Fig. 53. The line tie of *I* is made by winding the conductor once around the knob so both ends of the wire must be under tension to hold the wire in position. A tie-wire is used at *II*. In making up the tie-wire the slack can be drawn out of the conductor. A dead end or termination is shown at *III*. Where it is necessary to change the direction of a run to get the conductor to an outlet or for any other reason, tap-ties

IV, *V* and *VI* are used. It is not practicable to tie large conductors so they may be supported as at *VII*. See following note.



NOTE.—Methods of tying shown at I, V and VI, are not approved by the *Code* and should not be used except in temporary installations not subject to inspection. They should never be used in permanent work.

FIG. 53.—Methods of attaching to knobs.

77. **Tie-wires** must have an insulation equal to that of the conductors they confine and may be used in connection with solid knobs for the support of wires of size No. 8 or larger.

EXPOSED KNOB AND CLEAT WIRING

78. **Exposed knob and cleat wiring** is one of the cheapest and best methods when properly installed (*Standard Handbook*). It finds wide application in factories and mills and in places where appearance is of little consequence. It is also used for running feeders in tunnels and in specially built feeder shafts in fireproof buildings. The wires may be rubber-covered or provided with a slow-burning weather-proof installation. Slow-burning wire cannot be used in cellars, basements, under roofs or in other places exposed to moisture. The wires must be supported at least every 4½ ft., except in mill buildings where a support on each beam may be approved for wires No. 8 and larger if they are separated at least 6 in. The wires must, in dry places, be separated ½ in. from the surface wired over and spaced 2½ in. apart for voltages below 300. Above 300 volts and up to 550 volts, the wires must be separated from the surface wired over by at least 1 in. and must be spaced 4 in. apart. In wet places wires must be at least 1 in. from surface wired over for voltages below 300.

79. **Mechanical Protection of Exposed Surface Wiring.**—The wires must be protected on side walls from mechanical injury and, when crossing floor timbers in cellars or in rooms where they might be disturbed (Fig. 54), the wires must be attached by their insulating supports to the under side of a wooden strip or "running-

board" not less than ½ in. thick and 3 in. wide. Instead of running boards, guard strips on each side of and close to the wires may be substituted. The strips should be at least ⅞ in. thick and should be as high as the insulators. The wires should also be protected by porcelain tubes when passing over pipes (Fig. 55) or any other members.

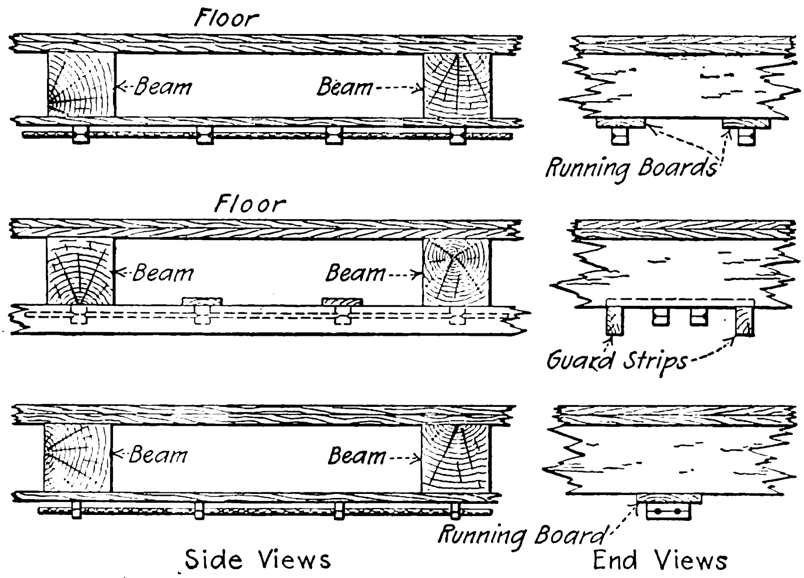


FIG. 54.—Protection of open-wiring on beams.

80. Suitable protection on side walls should extend not less than 7 ft. from the floor (Fig. 56). This may consist of substantial boxing, providing an air space of 1 in. around the conductors, closed at the top (the wires passing through porcelain bushed holes) or of approved wrought iron conduit or commercial wrought

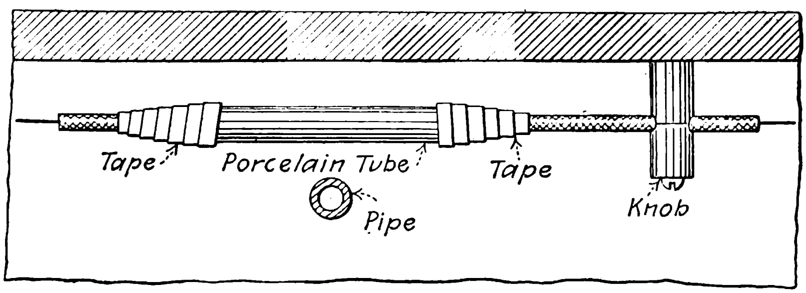


FIG. 55.—Protection of conductor passing over pipe.

iron pipe. When common pipe is used, the insulation of each wire must be reinforced by approved flexible tubing extending from the insulator next below the pipe to the one next above it. Where single-braid rubber-insulated wire is used in conduit the

same protection must be provided. Where double-braid-insulated wire is used in conduit the flexible tubing can be omitted, but each end of the pipe must be provided with an approved outlet box.

The two or more wires of a circuit, each with its approved flex-

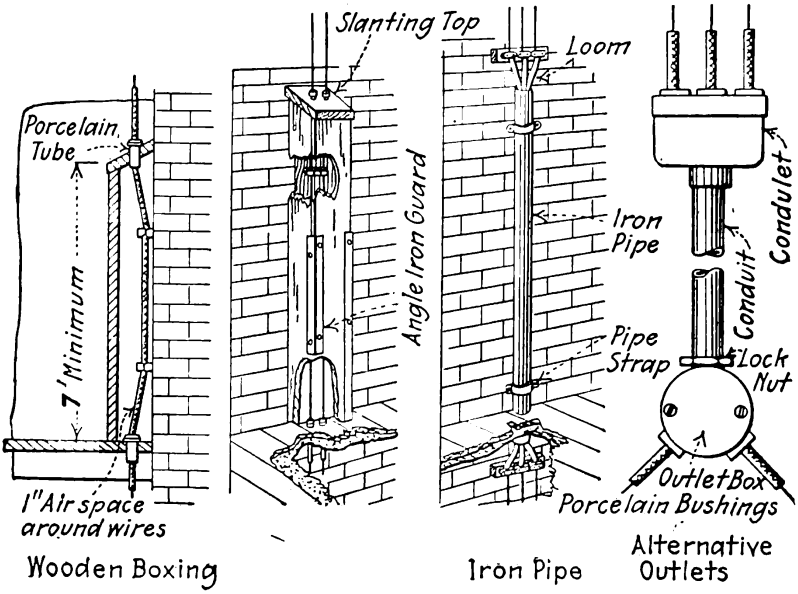


FIG. 56.—Protection of conductors on side walls.

ible tubing, if carrying alternating current, *must*, or if carrying direct current, may, be placed within the same pipe. In damp places the wooden boxing may be preferable because of the precautions which would be necessary to secure proper insulation if pipe were used. With this exception, however, iron pipe is considered preferable to wooden boxing, and its use is strongly urged. It is especially suitable for the protection of wires near belts, pulleys, etc. Fig. 57 shows an outlet arrangement for use at a floor that can be made with a square conduit outlet box.

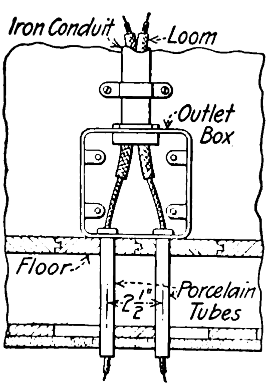


FIG. 57.—Another outlet arrangement.

81. Where conductors pass through floors, walls or partitions they must always be protected. Open-work wires can be protected with porcelain tubes (Fig. 58). The tube or bushing must be long enough to bush the entire length of the hole in one continuous piece or else the hole must first be bushed by a continuous water-proof tube. This tube may be a conductor, such as iron pipe, but in that case an insulating bushing must be pushed into each end of it, extending far enough to keep the wire absolutely out of contact with the pipe.

82. A tube for protecting a wire where it crosses another wire should always be so placed that the tube will not force the un-

protected wire against the surface supporting the conductors. The tube should always be on the inner wire (Fig. 59). If placed on the outer wire, the tube may force the unprotected wire against the surface as shown in Fig. 59, *I*. (*Electrical World*, April 6, 1912.)

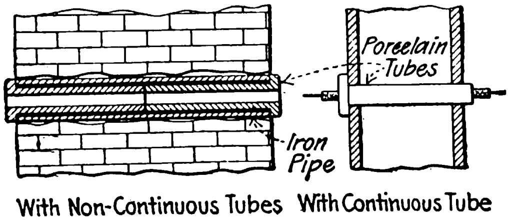


FIG. 58.—Protection through walls and partitions.

83. **A method of supporting open wiring in concrete buildings** is shown in Fig. 60. A round groove of $\frac{3}{8}$-in. radius is cast in the faces of the beams, by having $\frac{3}{4}$-in. half-round molding nailed in the forms. Wrought-iron yokes are bent to fit the grooves as

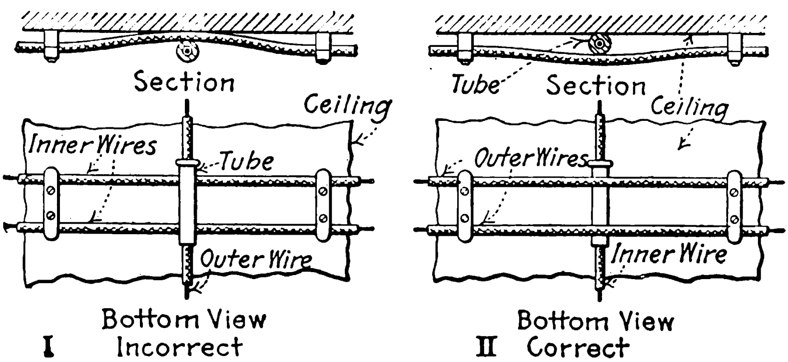


FIG. 59.—Methods of placing protecting tubes.

shown, and $\frac{1}{2}$-in. bolts clamp them in position. Although molding and conduit is shown supported in the illustration, wooden blocks can be bolted to the yokes and thereby open wiring can be supported.

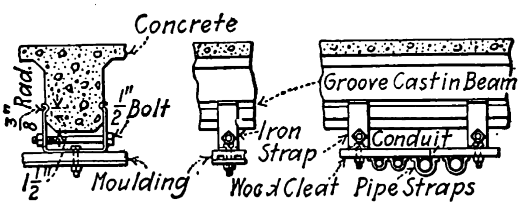


FIG. 60.—Supporting conductors on a concrete beam.

84. **Methods of carrying exposed wiring around and through beams** are illustrated in Fig. 61 which shows the tube and cleat arrangements. In Fig. 62 are shown some methods that can be used when wires are supported on knobs.

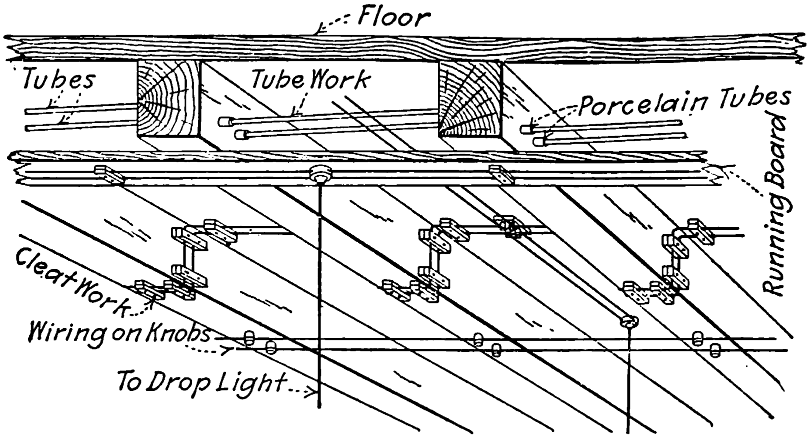


FIG. 61.—Open-work wiring in a mill building.

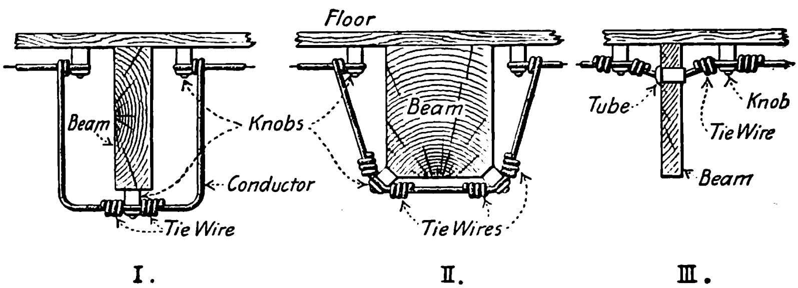


FIG. 62.—Open work wiring with knobs.

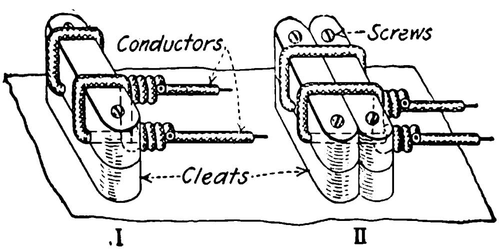


FIG. 63.—Dead-ending on cleats.

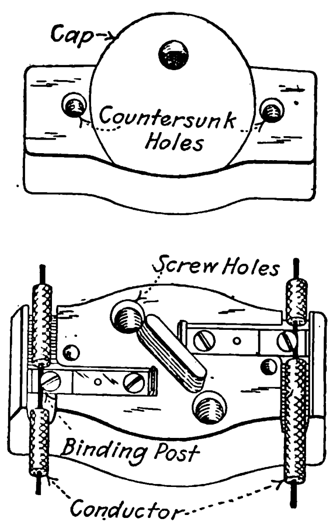


FIG. 64.—A cleat rosette.

85. **The method of dead ending on a cleat** at the end of a run is illustrated in Fig. 63, *I*. After the wire is passed through the groove the free end is given several short turns around the line. Where a long run is dead ended it is often advisable to so fasten two sets of cleats that one bears against the other so that both will assume the strain as shown at *II*.

86. **Rosettes for open surface wiring** are used to connect the drop cords for the incandescent lamps to the branch circuits. . A rosette with protected (concealed) contact lugs is preferable to one

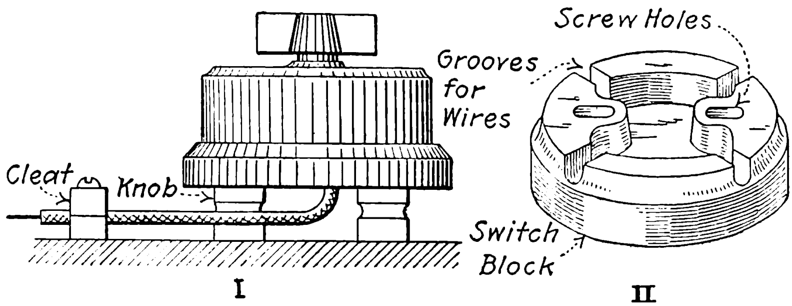


FIG. 65.—Supporting switches in exposed surface wiring.

with exposed lugs. Fig. 64 shows one good type. Another good method of supporting drop cords, particularly where there is vibration, is with the ceiling button described in 5 and illustrated in Fig. 76A.

87. **Switches can be supported in exposed surface wiring** as shown in Fig. 65. Small porcelain knobs may be used to support the switch (Fig. 65, *I*), which permits of the conductors being brought through the back of the switch without touching the supporting surface, however, this method is not approved by the National Code. Or the switch can be mounted on a commercial porcelain switch block (Fig. 65, *II*), which is an approved method.

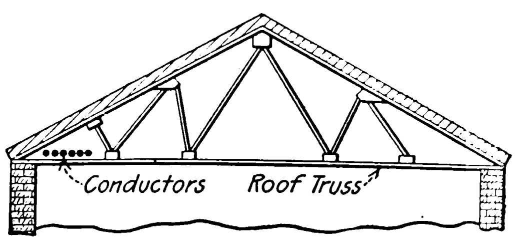


FIG. 66.—Conductors carried on roof truss.

88. **The different approved methods of exposed surface wiring** as arranged in a building of mill construction are illustrated in Fig. 61. Which method should be used in any particular case is a matter that is largely determined by the size of wire involved and other local conditions.

89. **In steel mill buildings heavy conductors may be carried** on the lower chords of the roof trusses (Fig. 66). This is a good

location as the conductors are out of the way and not liable to be disturbed. At each truss the conductors can be supported by one of the methods illustrated in Fig. 67. With the method of Fig. 67, *I*, the conductor merely rests in the insulator and the entire longitudinal strain is taken by strain insulators, attached to tightening bolts or turnbuckles, at the ends of the run. This method has the

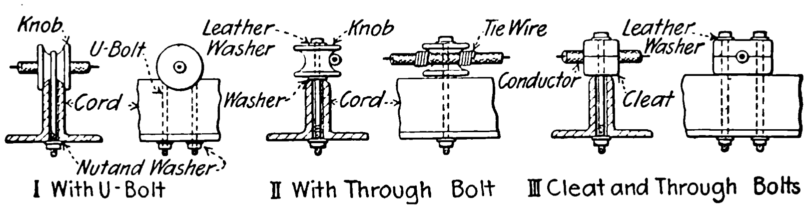


FIG. 67.—Attaching knobs to truss chords.

disadvantage that if the conductor breaks at any point or is burnt in two it will fall to the floor. The tie-wire method of *II* is seldom used, though it is satisfactory if cleats are not obtainable. (Split knobs or cleats must be used for conductors smaller than No. 8.) The cleat and through-bolt method of *III* is probably the best, all things considered. After the conductor has been drawn taut with the tightening bolts at the ends of the run the cleat bolts are tightened and each cleat then assumes its share of the strain. Tie-wires which are unreliable and which may cut into the insulation of the conductor are unnecessary. Leather washers should be used between the insulator and bolt to prevent breakage. Material that follows on Steel Mill Building Wiring is largely from an article in the *Southern Electrician*, December, 1912, by the compiler of this book.

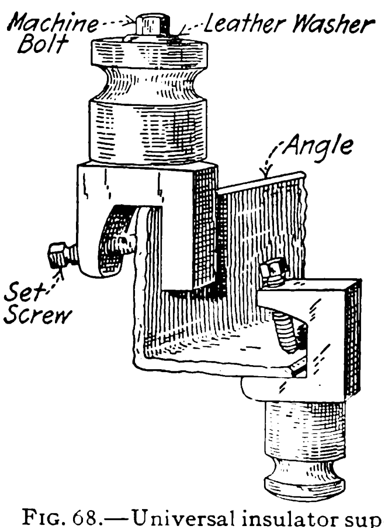


FIG. 68.—Universal insulator supports on an angle. (Note that split knobs must be used where conductors smaller than No. 8 are to be supported.)

90. For supporting conductors on steel angles the Universal Insulator Support (Figs. 68 and 69 and Table **91**) is a convenient fitting. It is of malleable iron and can be clamped on the flanges of steel beams, angles, channels, Z-bars, and on round, square and flat bars. It can be also attached to gas and water pipes, and to the edges of plates and tanks. Two insulators can be fastened to each support when necessary. Cup-pointed, case-hardened set screws are used. Leather washers should be used under the bolts that hold the insulators.

91. Dimensions of Universal Insulator Supports

(*Steel City Electric Co., Pittsburgh, Pa.*)

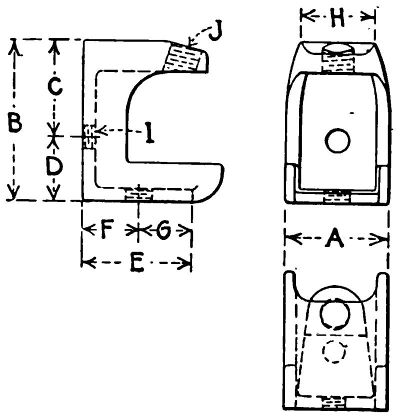


FIG. 69.—The universal insulator support.

A size in.	For insulators, numbers	B in.	C in.	D in.	E in.	F in.	G in.	H in.	I Dia. of tapped hole	J Dia. of set screw furnished
1	5, $5\frac{1}{2}$	$1\frac{1}{2}$	$\frac{7}{8}$	$\frac{5}{8}$	$1\frac{1}{16}$	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{5}{16}$
$1\frac{1}{2}$	10, 4, $4\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{3}{4}$	$\frac{5}{8}$	$1\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{16}$	$\frac{7}{16}$
2	1, 3, 3 W.G., $3\frac{1}{2}$, 24	2	1	1	2	1	1	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{1}{2}$
$2\frac{1}{2}$	25, 29, 34	$2\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{5}{8}$

92. **For supporting conductors on steel columns** a wooden base-board for the cleats clamped to the column with hook-bolts,

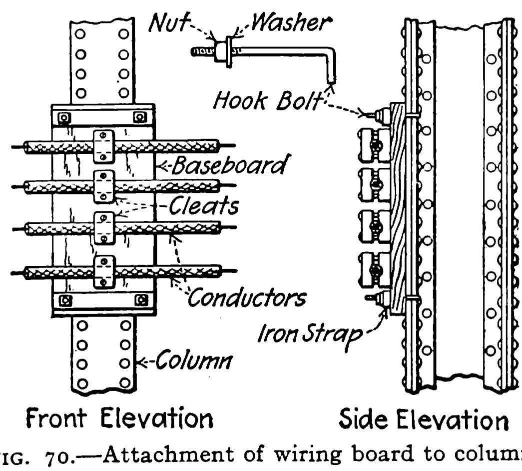


FIG. 70.—Attachment of wiring board to column.

Fig. 70, is a good arrangement. The board must be cut out in back for the rivet heads in the column. Strap iron cleats through which the hook-bolts pass prevent warping and splitting.

93. **Wire-racks** are used to support conductors, principally heavy ones, where there are many conductors in the run. The conductors should have flame-proof or slow-burning insulation. A wire-rack can be made of wood fashioned into a framework some-

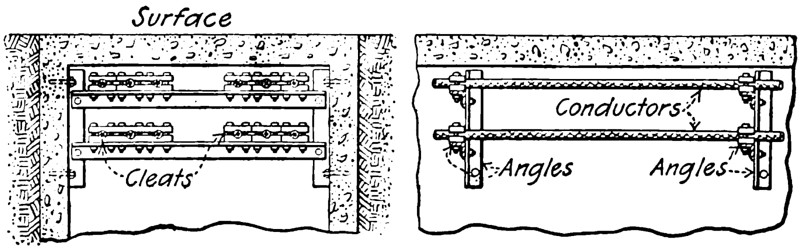


FIG. 71.—Angle iron rack for conductors.

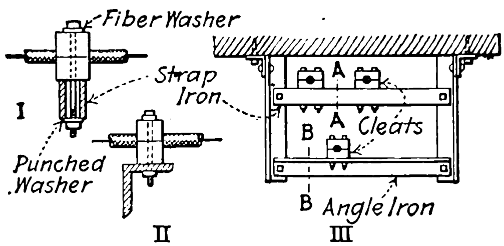


FIG. 72.—Rack composed of angles and strap iron.

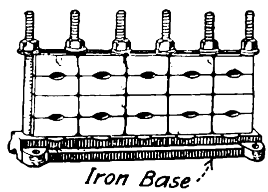


FIG. 73.—A commercial insulator rack.

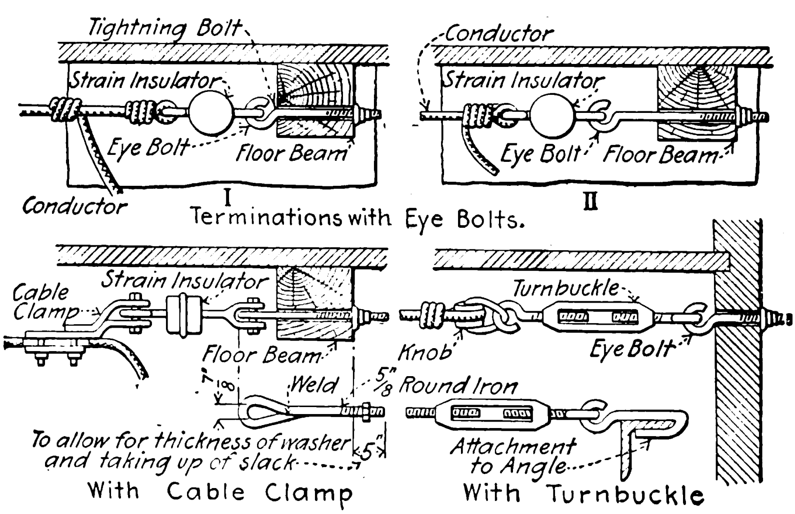


FIG. 74.—Methods of terminating conductors.

what along the lines of the steel ones of Figs. 71 and 72. The cleats insulating the conductors are held to the frame with wood screws or, preferably, with machine or stove bolts. A commercial wire rack with a cast-iron base that can be bolted to any surface is shown in Fig. 73. Generally a steel-frame rack is preferable to a

wooden one. The rack of steel angles of Fig. 71 was designed for installation in the top of a pipe tunnel. The insulators are held to the cross angles with bolts with a leather washer under the head of each. The structural steel rack of Fig. 72, *III*, is arranged for supporting from a ceiling. Angle cross-arms can be used as at *II*, or the cross-arms can each be formed of two iron straps as at *I*. With the two-strap method, drilling for the cleat bolts is unnecessary and the cleats can be shifted along the arm into any desired position and there clamped fast. Strain insulators engaging in turnbuckles or tightening-bolts should be used at the ends of each straight run to assume the strain and to provide for tightening or else the arms and cleats at the run ends should be reinforced to assume the stress that will come on them.

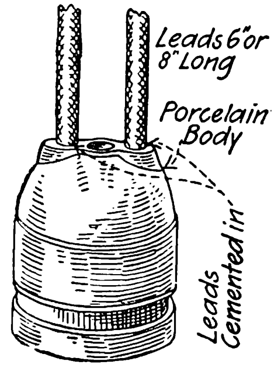


FIG. 75.—Weatherproof socket.

94. Methods of Terminating Heavy Conductors.—At the ends of all important open-wire runs of wires larger than, say, No. 8, strain insulators engaging in some wire-tightening device should be used. Fig. 74 illustrates some methods. Either tightening-bolts or turnbuckles can be used. The insulator may be of the type extensively used in trolley line construction as in *I*, *II* and *III*, or it may be a heavy knob (*IV*), held to the tightening device with stout wire. Where a run changes direction a cable clamp (see index for a further descrip-

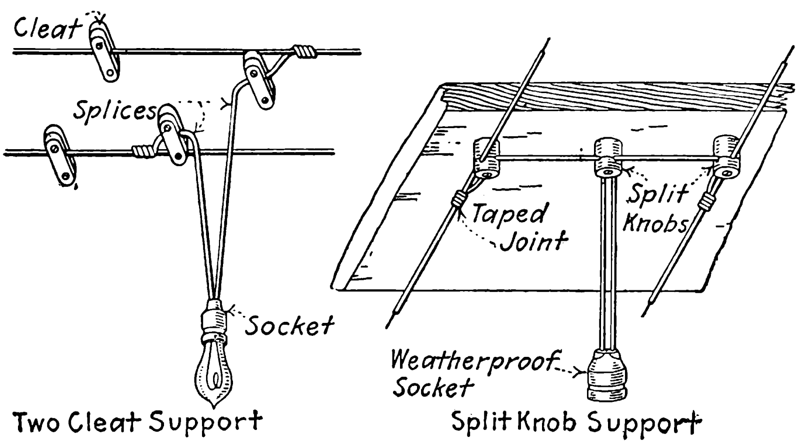


FIG. 76.—Short weatherproof pendant.

tion) can often be used with economy, particularly with large conductors. Where a cable clamp is used it is unnecessary to cut the conductor to change its direction and the necessity of making-up turns about the line wire as in *I* and *II* is eliminated.

95. Water-proof Pendants (*Factory Mutual Wiring Rules*).—For incandescent lamps in wet places, approved water-proof sockets should be used. These sockets should be suspended by

separate, *stranded*, rubber-covered wires, soldered to the socket leads and also to the overhead wires. Where the pendant is over 3 ft. long, the wires should be twisted together. The entire weight of the pendant should be borne by cleats or some other independent means, in order to prevent any strain on the connection to the overhead wires. (See Figs. 75, 76 and 77.)

96. In wiring in damp places such as in dye-houses, stables and breweries, wires should be rubber insulated, and separated at least 1 in. from the surface wired over, preferably by knobs. Solid knobs are preferable to split ones, because there is more liability of current leakage to the screw of a split knob. They should be separated by at least $2\frac{1}{2}$ in. for voltages up to 300 and 4 in. for voltages up to 600. Greater separations

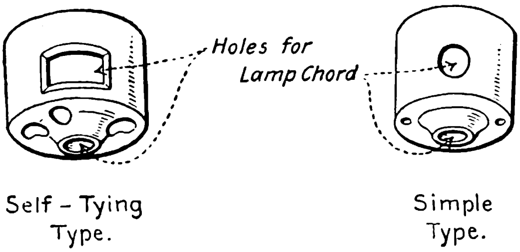


FIG. 76A.—Ceiling buttons.

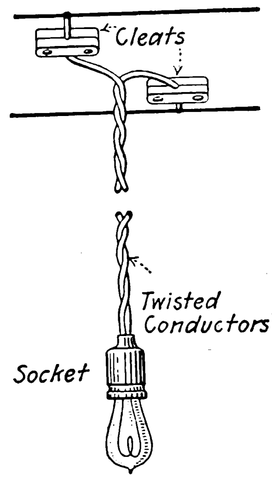


FIG. 77.—Long weather-proof pendant.

are preferable. Conductors **on side walls** should be protected preferably with well-painted wooden boxing (see 80), but conduit can be used. Molding is not permitted in damp locations. Sockets and other fittings in such places should be designed to withstand moisture.

97. Where conductors cross damp pipes they should be carried over rather than under, so that drippings will not strike the wires. Porcelain tubes, securely taped to the conductors, should be placed on the conductors over the point where they cross.

98. Sockets for damp places should be of porcelain and hard rubber, or composition weather-proof, or, as they are sometimes called "water-proof" (Fig. 75). Unless made up on fixtures they should be hung by separate stranded, rubber insulated wires, not smaller than No. 14 B. & S. gage, which should preferably be twisted together when the pendant is over 3 ft. long. The leads furnished in weather-proof sockets are 6 in. or 8 in. long, but longer ones can be supplied on special order. The socket leads should be soldered direct to the circuit wires but supported independently of them. Fig. 76 shows a short drop and Fig. 77 a long one; both figures illustrate the method of using cleats to remove the stress from the line conductors. Water-proof sockets are always keyless. Porcelain sockets are easily broken; hence, although their use is not formally approved by the Underwriters', brass-shell sockets

thoroughly taped and coated with water-proof paint, are sometimes used. Where not liable to be broken, porcelain sockets are the best.

99. Receptacles for damp places are shown in Fig. 80. They are especially designed to withstand moisture, but should always be supported on porcelain knobs. The rubber insulated leads extend 6 or 8 in. from the body. The leads should be soldered directly to the line wires and the joint well taped.

100. Wiring troughs are sometimes used in damp places. (Fig. 78.) The troughs protect the conductors from drippings, but not from water that condenses on them out of the atmosphere. In assembling wiring troughs, abutting edges should be coated with

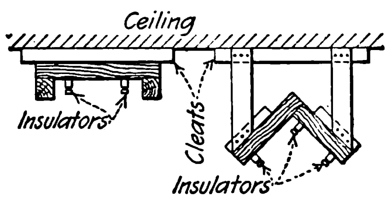


FIG. 78.—Wiring troughs.

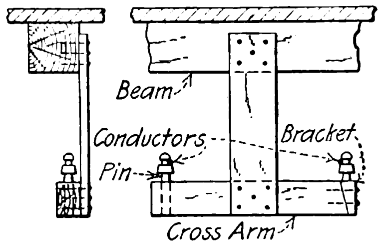


FIG. 79.—Cross-arm support.

tar or with a thick water-proof paint. Screws smeared with paint should be used to hold the pieces together and the screw heads should be painted. A wiring trough in addition to keeping drippings from the conductors, constitutes a mechanical protection for the conductors. The wiring trough serves the same purpose as a running board in this respect.

101. Porcelain or Glass Petticoat Insulators Probably Form the Best Support for Wiring in Damp Places.—These are the same insulators that are used on out-of-door pole lines. There is apt to be considerable electrical leakage in damp places with ordinary

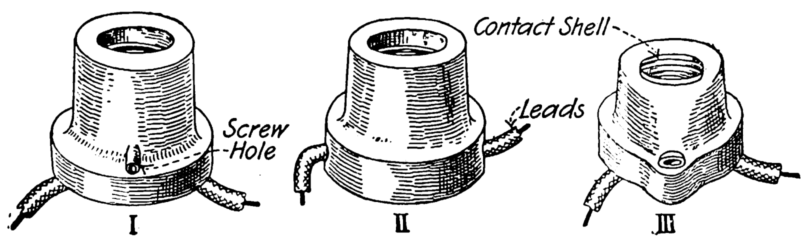


FIG. 80.—Receptacles for damp places.

knobs and cleats, and the long creepage distance provided by petticoat insulators constitutes good protection against this. The insulators are supported on thoroughly painted wooden pins or brackets, which are held by small cross-arms (Fig. 79). In no case should the insulator be mounted upside down. Glass or porcelain knobs, mounted on a small cross-arm, are sometimes used instead of insulators, but are not as good from an insulation standpoint. The advantage of mounting them on the arm is that an ample separation from the surface wired over is thus provided. The cross-arm and support should be thoroughly painted with a waterproof paint or tar.

102. **Joints and splices in damp places** must be soldered with great care and should be thoroughly taped. A thorough painting of the tape wrapping, with a water-proof compound, asphaltum or tar, will protect against the entrance of moisture. Splices should be avoided in damp places, but where necessary, they should be located at some distance from a point of support, because the insulation resistance of the insulation around a splice is less than that of equal length of perfect wire.

103. **Switches and fuses for wiring in damp locations** should, if possible, be located outside of the damp room and in a dry place. Where it is impossible to locate them outside of the damp room they should be mounted within a box that can be kept dry, or on porcelain knobs (Fig. 81). Cabinets thoroughly treated with water-proof compound are preferable to metal ones. A switch-and-fuse cabinet similar to that of Fig. 82 can be made of $\frac{7}{8}$-in. stock. It is lined with well-painted asbestos board and mounted away from the damp wall on porcelain knobs. The constantly burning incandescent lamp keeps the box dry. A glazed hole in the cover serves to show the location of the box in a dark room.

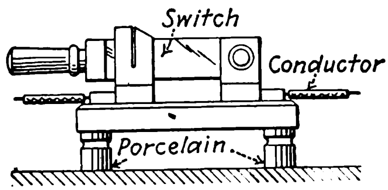


FIG. 81.—Knife switch mounted on porcelain knobs.

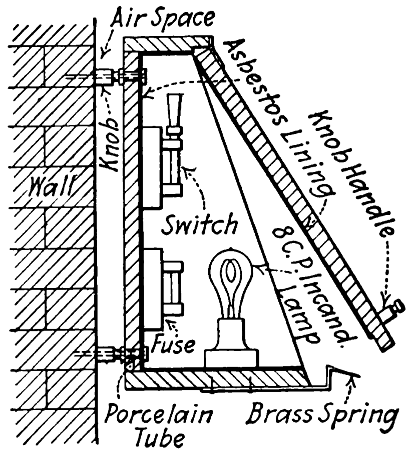


FIG. 82.—Switch and fuse box for damp places.

104. **Wiring in Packing Houses.**—Moisture, ammonia and other corrosive vapors are encountered, hence, fuses and switches cannot be installed exposed as in ordinary open-work wiring. There is also danger of mechanical injury to ordinary open-work wiring. Switches should be installed in cabinets similar to that described in 103. Ordinary brass sockets will give trouble; those of the keyless type of porcelain, hard rubber or composition may be used. Open wiring on knobs is usually preferable because of the trouble encountered with conduit due to corrosion, even if it is thoroughly painted. The rusting gives the most trouble at the threads in the couplings.

To support the knobs, blocks of wood impregnated with asphaltum, tar or shellac are nailed to the wall or ceiling. The blocks provide ample clearance between the surface and the conductors. A method of carrying conductors that largely prevents moisture from reaching them and the knobs is shown in Fig. 79. Tie knobs are considered preferable to split knobs for this work because of the better insulating properties of the tie knobs.

105. **Brewery wiring** is subject to conditions similar to, though less severe than, those affecting packing-house installations and in general should be treated accordingly. Conduit can be installed to advantage in many locations. In the others, open wiring on knobs can be effectively used, especially in the compressor rooms, the wash rooms and in the tank cellars. Weather-proof switch boxes of the type herein before described should be used unless switch cabinets are installed.

106. **Wiring in Flour, Cereal and Planing Mills.**—Switches and fuses should be installed in dust-tight cabinets, as should starting rheostats for the motors. There are on the market dust-proof switch cabinets, starting boxes and other appliances which should be used in preference to homemade ones. Lamps installed in sockets attached to side walls involve a fire risk as the dust may deposit on them and ignite. Suspend the lamps from the ceiling. Since the dust may get into them and be the cause of an explosion or a short-circuit, key sockets should not be used. Wrought-iron conduit work is probably the preferable type of wiring.

107. **Chemical Works Wiring.**—Lead cable sheaths, iron conduit and slate are usually attacked by the vapors, while porcelain, as a rule, is not. The following method of installing conductors has been used with success in one prominent works. Conductors having weather-proof insulation are installed in hard-wood molding and are buried in tar in the grooves. Both the molding base and the capping are served with a thick coating of tar before they are installed and also afterward. For lamp outlets, molding receptacles are used. Before each lamp is screwed into its socket, a ring of heavily tarred wire is slipped over the base. This ring seals the opening and prevents the entrance of corrosive vapors into the receptacle. The entire installation—molding and fittings—should be thoroughly coated with tar.

108. **Wiring in Dry Kilns** (H. G. Wilson, *Electrical Review*, Feb. 17, 1912).—Rubber-covered wire is of little practical value in these excessively hot places either on knobs or cleats or in conduit, as after a comparatively short time the rubber is thoroughly dried out and becomes brittle and crumbles. Dry kilns are usually constructed of brick with a structural steel framework. Experience has shown that wooden blocks fastened to the walls and framework shrink to quite an extent and in some places char with the heat. Consequently, they become loose and fail to sustain the wires. Profiting by experience, rubber-covered wire, wooden blocks and conduit were eliminated altogether from a certain dry-kiln job. Asbestos-covered wires with a 6-in. separation and not less than 1 in. from the surface wired over were installed. Supports were placed every $4\frac{1}{2}$ ft. Split knobs fastened securely to the iron framework with bolts were used, the holes being drilled through so that nuts held them in place and, where this was impossible, the holes were drilled and tapped with threads corresponding with those on the bolts. For supporting the wire on brick side walls, iron brackets were made which carried knobs.

Porcelain wall sockets were used where practicable. For drop lights another Code rule was "stretched," as No. 14 solid asbestos-

covered wire had to be used. The drop wires were permanently separated, from their joints on the circuit wire to the porcelain sockets, by cleats held together by stove bolts, thus giving a $2\frac{1}{2}$-in. separation, and the taps were anchored by split knobs, one for each wire. Fuses, switches and cut-out cabinets were placed outside of the kilns.

109. Wiring in Metal Refineries (H. G. Wilson, *Electrical Review*, Mar. 2, 1912).—While, as a rule, the motors employed in plants of this kind can be placed beyond the reach of the detrimental effects of heat and acid fumes, the use of squirrel-cage induction motors is to be preferred, since these have no sliding contacts. When these are used it is best to paint the insulation of wires exposed to acid fumes with hot tar. If direct-current motors must be employed, these should be completely inclosed to protect them from the effects of dust, which is always prevalent.

Overhead wiring in furnace buildings, in which it is always very hot, should preferably be with asbestos-covered conductors on cleats or split knobs which hold them 1 in. from the surface wired over and 6 in. apart. Screws should be used rather than nails and leather washers in securing the knobs or the cleats, for in a room where the temperature is from 125° to 150°, as it is in these, leather-heads soon become practically worthless.

When installing wiring in metal refineries already completed, as much of the work as possible should be done outside the rooms, since on the inside the acid fumes and heat may be very trying to workmen. This outside work may include such jobs as loosely screwing the insulators to the supporting blocks, cutting conductors to the proper length, and making splices and taps for drop lights. With this done, the installation can be rapidly completed.

Only the best workmanship and material should be employed; for, since the making of repairs is apt to be very trying, the highest possible degree of permanency is desirable. Contractors, in submitting bids on jobs of this kind, should make a generous allowance for labor, as only about half the work can be accomplished as it would be under better conditions. This precaution applies only where the wiring must be done after the plant is running.

Wiring in furnace buildings for switch legs and on sidewalls should be placed in rigid conduit as a protection from mechanical injury. Porcelain sockets seem to withstand the conditions better than others. Single-wire cleats or split knobs should be used rather than rosettes, with each wire anchored separately. Steel cut-out cabinets are preferable, as wooden asbestos-lined boxes soon dry out and become defective unless they are thoroughly seasoned. All openings around wires should be filled to prevent the entrance of dust, which will, in time, cause poor contacts, and for this same reason snap switches are preferred to knife switches. No. 14 rubber-covered stranded wire for drop cords can be used to good advantage.

A permanent method for wiring the copper sulphate houses is still being sought, as the sulphuric acid fumes rot the braiding on the wire and also have a dehydrating effect on the rubber, which soon dries it out and renders it useless as an insulator. The atmos-

phere is moist due to the escaping steam from the vats. This may render other insulations than rubber unreliable. Conduit work and lead-covered twin wiring on insulators have been used with only fair results. However, the conduit does not protect the insulation from the acid fumes. The difficulty of readily making a good joint in the lead-covered cable has made its use undesirable.

A certain metal refinery which had been annoyed with breakdowns in the electric wiring due to the causes indicated, tried the following construction. The first cost was high, but several years' use of the system has shown the investment to be a wise one. Sound hardwood molding was thoroughly warmed and generously painted on all surfaces with hot tar, so that the pores were well filled. The rubber-covered wire was coated with tar. Care was taken that no uncovered spots were left. The wires then were placed in the grooves in the molding and the space that then remained unfilled was also tarred with as much tar as could be made to adhere. The capping was then put in place after receiving a coat of tar on all surfaces. The molding was placed on its supporting surface at a time when it was comparatively dry and a strip a little wider than the molding was painted with tar. Porcelain molding receptacles were used wherever practicable and for drop lights No. 14 rubber-covered stranded wire was employed.

MOLDING WIRING

110. **Wooden molding wiring** is frequently used for additions to existing installations and where a low-priced job of neat appearance is required. Its use is prohibited by the Underwriters in damp places, in rooms where there are fumes or in elevator shafts. (Iron conduit should always be used in elevator shafts.) Approved fittings are made whereby molding wiring can be used in combination with the other methods. Single-braid, rubber-insulated wire must be used in molding. Where a circuit in molding runs into conduit, double-braid wire, spliced to the single-braid molding wire, must be used in the conduit. Where wire from molding runs into flexible tubing or loom, single-braid wire may be used in both molding and flexible tubing. (The material that follows on Molding Wiring is taken largely from articles on the subject written by the complier of this book and printed in *The Practical Engineer* and in *Electrical Engineering*.)

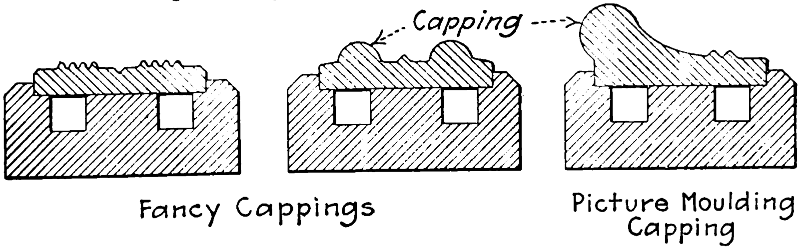


FIG. 83.—Special cappings.

111. **Wooden molding** is made in many forms. The standard designs are shown in Fig. 86 for two-wire, and Fig. 87 for three-

wire. For first-class work hard-wood molding and capping matching in finish the trim of the room in which it is installed can be used. Capping of various designs can be purchased (Fig. 83). When buying molding one should see that it conforms to code requirements. Second-rate material which may be cross-grained or knotty should be avoided because it will be more expensive in the long run than first-class stock. Patented moldings (Fig. 84) are

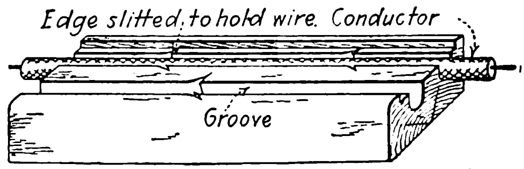


FIG. 84.—Kirkpatric's hold-wire molding.

obtainable which will retain the wire when it is pressed into the grooves, making the use of brads for temporary support unnecessary. Although it is recommended by the Code, hard-wood molding is little used. Georgia pine, oak or similar hard-wood moldings cost about twice as much as the ordinary white wood (soft wood) stock. Table 114 gives the dimensions of standard molding.

112. **Molding is supported** on lath and plaster with long, small-diameter, flat-head screws. Nails are permissible when running over a wooden surface. On brick walls, the wall is drilled and plugged and a wood screw turning into the plug supports the molding. In fire-proof buildings using hollow tile partitions and arches toggle bolts (Fig. 85) are used. Wood screws have been used for this work by drilling holes, of a slightly smaller diameter than the screw, in the tile. Then turning the screw into the hole causes it to cut its own thread. Base should be supported every $1\frac{1}{2}$ ft. to every 3 ft. and the capping somewhat more frequently. With very large molding support points should be even closer together.

Either screws or nails can be used to support capping and they should, if feasible, pass entirely through the capping and into the wall. The saw cuts for two pieces of base where they abut should be at an angle and so that one piece will support the other. Where feasible, the nut on a toggle-bolt should be placed outside the capping. If placed under the capping there is a possibility, particularly with the smaller moldings, of cutting away so much of the tongue that the toggle-bolt nut will bridge across the conductors.

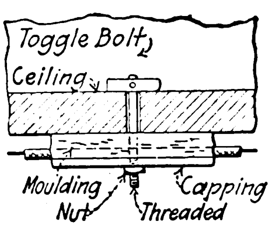


FIG. 85.—A toggle bolt supporting molding.

113. **When erecting wooden molding on side walls or partitions,** it should never be installed where it will be subjected to mechanical injury and as a general proposition should not be used within 6 ft. from the floor. Conduit or pipe protection (see 80) is preferable in such locations.

114. Standard Two- and Three-wire Wooden Molding

(*Kirkpatric Manufacturing Company*)

The products of various manufacturers vary somewhat in dimensions. All dimensions are given in inches.

A Size of groove	Will accommodate wires		B	C	D	E	F
	Solid	Stranded					
Two-wire molding							
$\frac{1}{4}$	14 to 12	......	$1\frac{1}{2}$	$\frac{5}{8}$	$1\frac{1}{8}$	$\frac{3}{16}$	$\frac{13}{16}$
$\frac{3}{8}$	10 to 8	8	$1\frac{3}{4}$	$\frac{3}{4}$	$1\frac{3}{8}$	$\frac{3}{16}$	$\frac{15}{16}$
$\frac{1}{2}$	9 to 4	5 to 6	$2\frac{1}{8}$	1	$1\frac{5}{8}$	$\frac{7}{32}$	1
$\frac{5}{8}$	3 to 0	4 to 1	$2\frac{1}{2}$	$1\frac{3}{16}$	$1\frac{7}{8}$	$\frac{7}{32}$	$1\frac{1}{8}$
$\frac{3}{4}$	.....	0 to $\frac{4}{0}$	$2\frac{7}{8}$	$1\frac{1}{4}$	$2\frac{3}{16}$	$\frac{1}{4}$	$1\frac{3}{8}$
$\frac{7}{8}$	.....	$\frac{4}{0}$ to 250,000	$3\frac{1}{8}$	$1\frac{3}{8}$	$2\frac{7}{16}$	$\frac{1}{4}$	$1\frac{1}{2}$
1	.....	250,000 to 500,000	$3\frac{5}{8}$	$1\frac{5}{8}$	$2\frac{13}{16}$	$\frac{1}{4}$	$1\frac{3}{4}$
Three-wire molding							
$\frac{1}{4}$	16 to 12	......	$2\frac{3}{8}$	$\frac{11}{16}$	$1\frac{7}{8}$	$\frac{3}{16}$	$\frac{13}{16}$
$\frac{3}{8}$	10 to 8	8	$2\frac{3}{4}$	$\frac{13}{16}$	$2\frac{1}{4}$	$\frac{3}{16}$	$\frac{15}{16}$
$\frac{1}{2}$	8 to 4	5 to 6	$3\frac{1}{8}$	1	$2\frac{11}{16}$	$\frac{1}{4}$	$1\frac{1}{8}$
$\frac{5}{8}$	3 to 0	4 to 1	$3\frac{5}{8}$	$1\frac{3}{16}$	3	$\frac{1}{4}$	$1\frac{1}{4}$
$\frac{3}{4}$	.....	0 to $\frac{4}{0}$	$4\frac{1}{8}$	$1\frac{1}{4}$	$3\frac{3}{8}$	$\frac{5}{16}$	$1\frac{7}{16}$
$\frac{7}{8}$	.....	$\frac{4}{0}$ to 250,000	$4\frac{1}{2}$	$1\frac{3}{8}$	$3\frac{7}{8}$	$\frac{1}{4}$	$1\frac{1}{2}$
1	.....	250,000 to 500,000	$5\frac{1}{4}$	$1\frac{5}{8}$	$4\frac{1}{2}$	$\frac{1}{4}$	$1\frac{3}{4}$

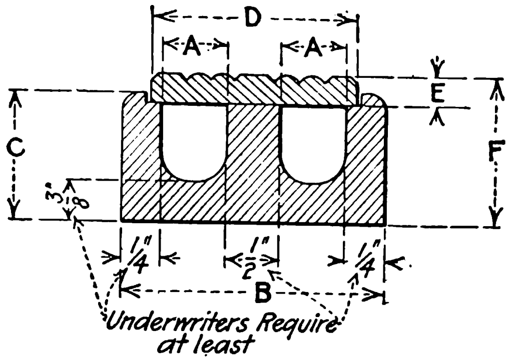


FIG. 86.—Section of two-wire molding.

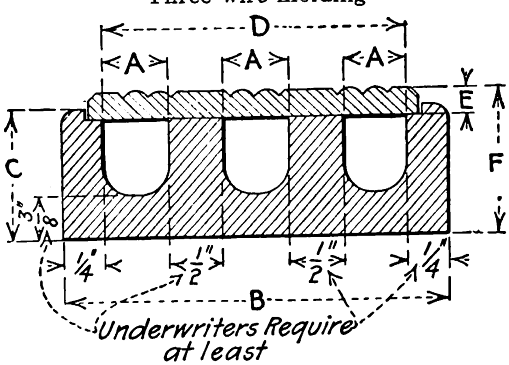


FIG. 87.—Section of three-wire molding.

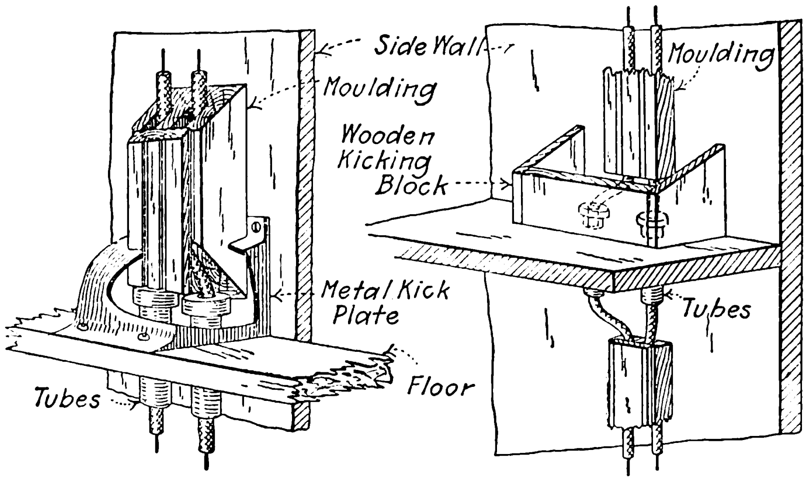


FIG. 88.—Molding kick plates.

115. **In running molding circuits through floors where no interference is probable, the molding can be run almost to the floor** provided protection such as a kick plate (Fig. 88) is installed at the floor. This construction is permissible in residences, offices and similar places. An iron pipe may be used instead of a kick plate to protect wires from molding where they pass through a floor (Fig. 89), provided the wire within the pipe is encased in loom. The pipe should extend 4 to 6 in. above and below the floor.

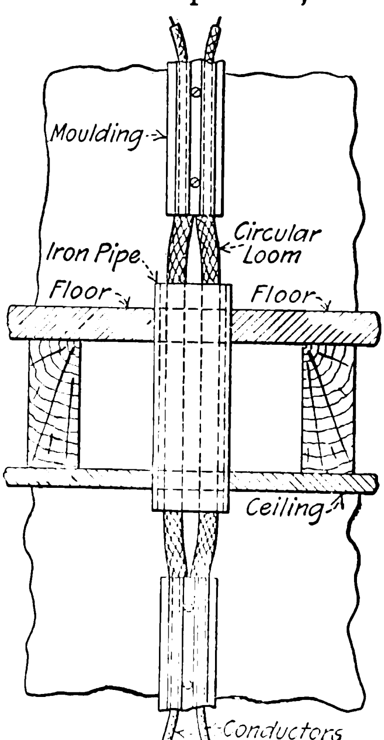


FIG. 89.—Iron pipe protection through floor.

116. **When running wooden molding on outside brick walls** a cleat or backing of wood ½ in. or ⅞ in. thick, thoroughly painted with a moisture-proof paint, should be first nailed to the wall (Fig. 90) to which the base can be fastened. The backing protects the molding from the moisture which often exists in the outer walls of brick buildings.

117. **Mitering molding at** turns should be done as suggested in Fig. 91, *I*. A fine-tooth miter saw and a miter-box, preferably a metal one, can be used to advantage. A rough and ready method that cannot be considered safe wiring is shown at Fig. 91, *II*. The capping hides the botch job.

118. **Molding can be bent** around the curved surfaces often

found in modern office buildings as shown in Fig. 92. Saw cuts are made in the base with the miter-saw. Moistening the base and capping renders it more easily bent. For first-class work, glue painted into the saw cuts before the base is formed to position will tend to better hold the base in shape.

119. The molding lay-out should conform to symmetrical designs in first-class work even if it is necessary to place "dead" molding to complete the design. It may be necessary to run

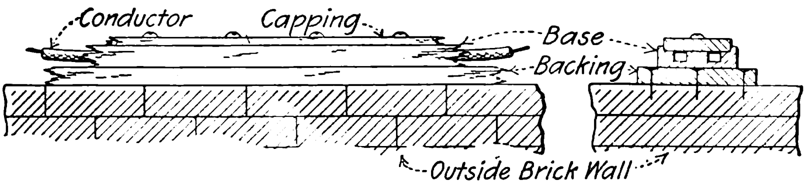


FIG. 90.—Molding on an outside brick wall.

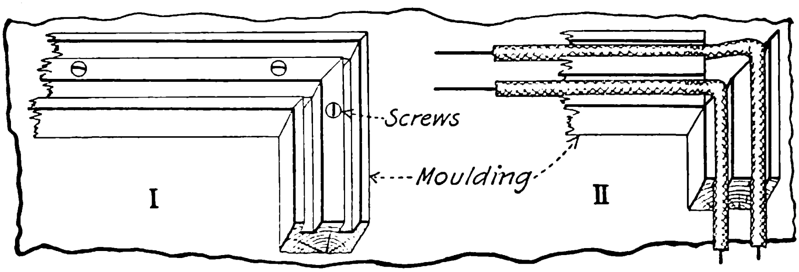


FIG. 91.—Right-angle molding turns.

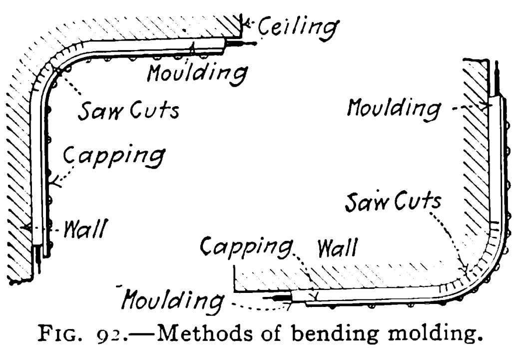


FIG. 92.—Methods of bending molding.

molding with picture-molding capping around the walls of an entire room even if that on three walls is dead. Fig. 93 shows an arrangement of dead molding on a ceiling.

120. To support wooden molding to the lower flanges of I-beams in fire-proof and structural steel buildings I-beam hooks, Fig. 94, which are punched from sheet metal and which can be purchased from supply dealers, are used. Wood screws passing through the hook enter the base and thus secure it in position. Where the span between beams is long it may be necessary to support a running

board with the beam-hooks and then fasten the molding to the running board.

121. **When placing wires in molding** that does not have one of the

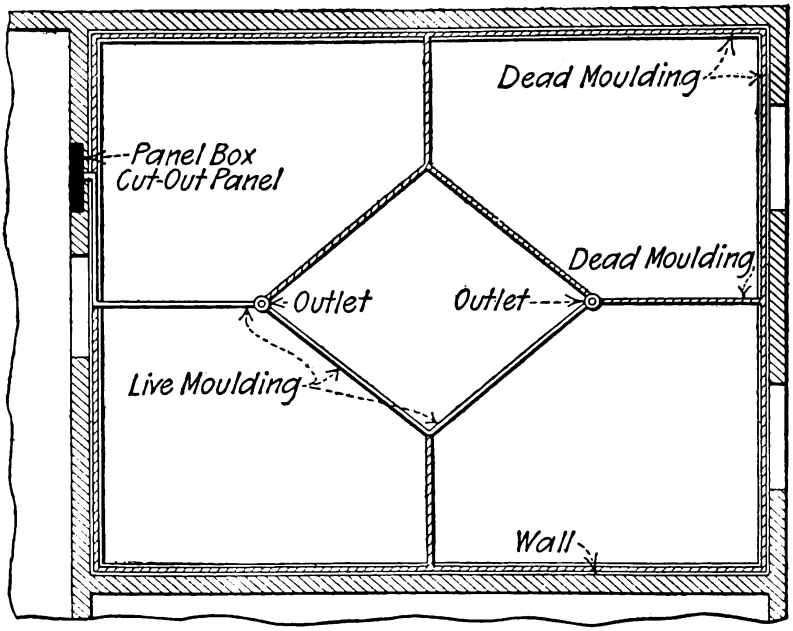


FIG. 93.—Dead molding to complete a design.

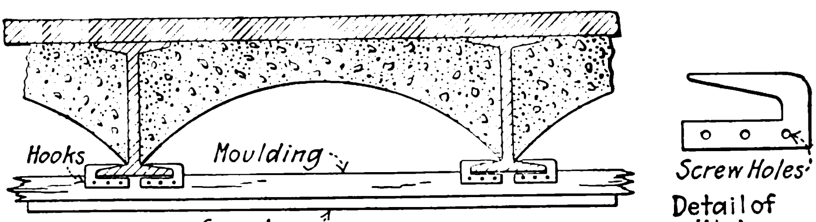


FIG. 94.—Method of supporting molding on I-beam flanges.

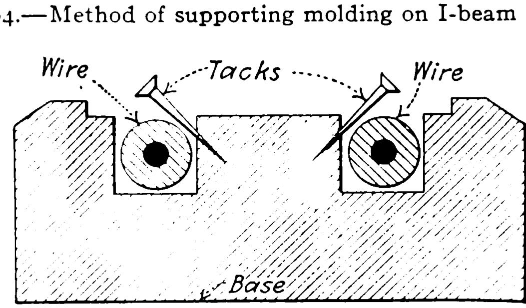


FIG. 95.—Brads holding wires.

patented "wire grip" features they can be temporarily held in the grooves with tacks or brads (Fig. 95) until the capping is placed.

122. In tapping off a branch in wooden molding wiring an approved "taplet" fitting (Fig. 96) must be used. It was formerly permissible to solder on the tap wires and bring one of them over the capping, but this is no longer permitted by the Underwriters. No joints or splices are permitted in molding wiring except at outlets or fittings.

123. A cross-over in wooden molding wiring is made with a fitting as in Fig. 97.

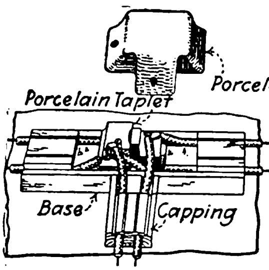


FIG. 96.—Molding taplet.

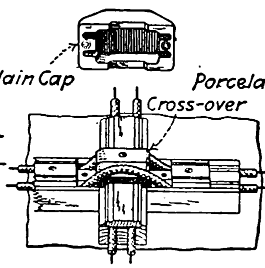


FIG. 97.—Molding cross-over.

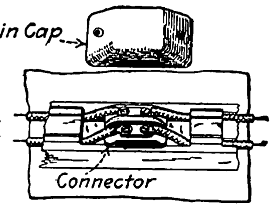


FIG. 98.—Molding connector.

124. A joint in wires in wooden molding must be made with an approved fitting (Fig. 98). No joints or splices are permitted within the molding itself, that is, the wires must be continuous from outlet to outlet.

125. In wiring for side-wall outlets in a molding installation the molding can often be advantageously carried around the base-board (Fig. 99) and the taps to the outlets carried down within the partition in loom. The taps are fished down within the partition.

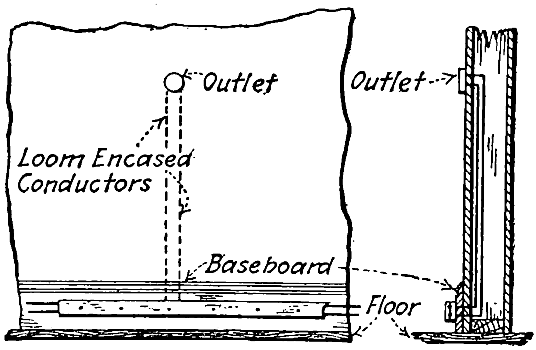


FIG. 99.—Molding on baseboard.

126. Special Fittings are Made for Connecting Conduit Circuits to Molding Circuits.—Fig. 100 illustrates one of the many forms. These compact fittings can be substituted for the bulky and unsightly pressed steel outlet boxes.

127. In carrying wires from conduit to molding, the single-braid molding wire must be spliced to the double-braid conduit wire

within an outlet box (Fig. 101). Flexible conduit or porcelain bushings must protect the molding wires where they enter the box. Where the junction between molding and conduit systems is on a wall or ceiling wherein the conduit is embedded, the connection may be made as at *II*. An additional outlet box is attached over the old one with long screws.

128. **When using molding in combination with flexible conduit or flexible steel armored cable for old building wiring,** flexible tubing or steel armored conductors are used for the portions of the installation where they can be readily drawn in and molding is used for the balance. Fig. 102 (Knox, *Electric Light Wiring*) shows such an installation. The circuits in the hall are carried in molding, but from the hall to the outlets they are in flexible tubing and are fished over from the hall. Where flexible fibrous conduit and molding are used steel outlet and splice boxes are not required so the work can be economically done and it looks well when finished. Auerbacher says (*Electrical Contracting*): "If ceilings are furred, an apartment of this kind should be wired in two days by a journeyman and helper without breaking walls or ceilings.

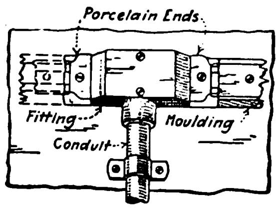


FIG. 100.—A "condulet" molding fitting.

129. **Molding receptacles and rosettes** (Fig. 103) should be of the types for which the backing does not have to be cut for their installation. Fittings are on the market which require the cutting of the backing and these should be avoided.

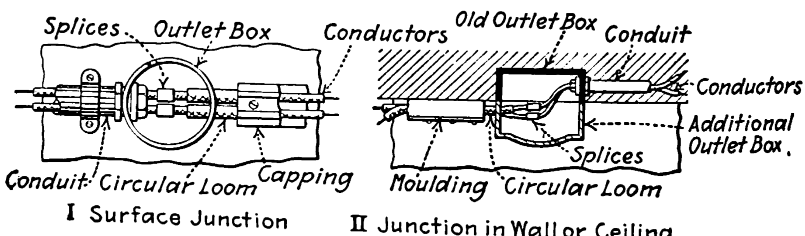


FIG. 101.—Molding-conduit junction.

130. **Switches for molding** are ordinary snap switches mounted on either a wooden (Fig. 104, *I*) or a porcelain (Fig. 104, *II*) switch block. Porcelain is preferable but a wooden block can be made on the job if a porcelain block is not available.

131. **Molding for store-window lighting** can be erected as in Fig. 105. This is a good method where expense must be a minimum. (Auerbacher, *Electrical Contracting*.) An aluminum reflector requiring no shade-holder can be used. The reflectors are spaced 6 in. to 12 in. The molding can be made up complete with wires and receptacles in the shop and can be erected in a short time. For further information see the section on *Illumination*.

132. **In wiring in molding for drop lights on a fire-proof ceiling** (*Electrical Contracting*, Auerbacher) (Fig. 106), if the panel has no

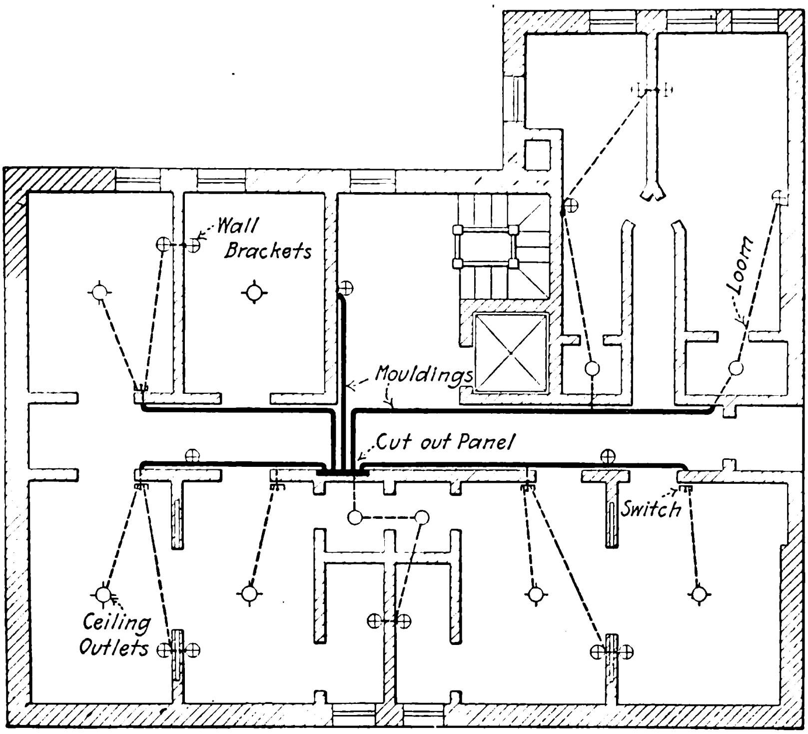


FIG. 102.—Combined molding and circular loom job.

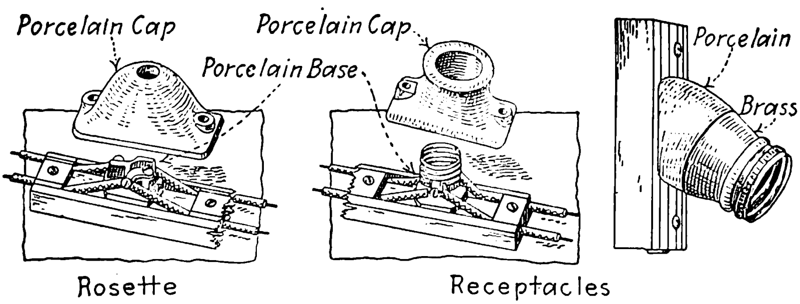


FIG. 103.—Molding rosette and receptacles.

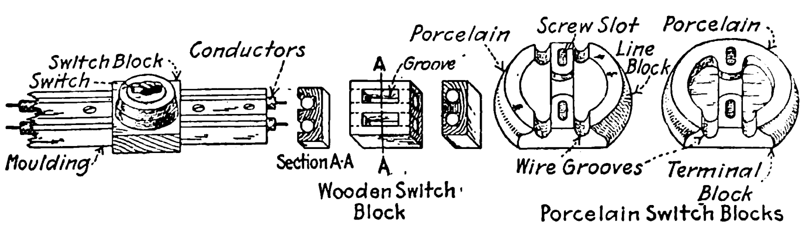


FIG. 104.—Switches on molding.

directory it is necessary to make a diagram of the circuits and to tap the outlets in such a manner that the 660-watt limit per branch circuit is not exceeded. When estimating on such work the wireman should ascertain the capacity of the existing outlets so that his estimate will include any additional circuit runs to the panel that may be required. The molding circuits are tapped to the

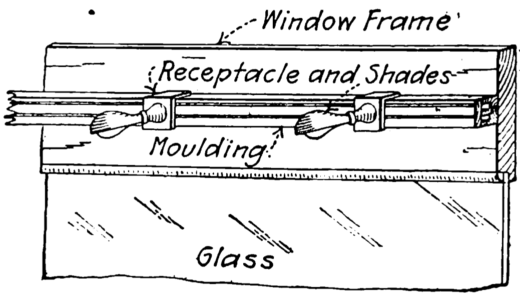


FIG. 105.—Show-window wiring in molding.

conduit outlets as described elsewhere. Fig. 106 shows the wiring plan of a fire-proof building ceiling for which the existing outlets have been tapped and wire run in the molding as described. The dead portion of the molding is indicated by the shaded parts.

133. **Fixtures in molding wiring installations** should be supported on a wooden block (Fig. 107) about 5 in. in diameter. The block provides a substantial support for the fixture, constitutes a backing

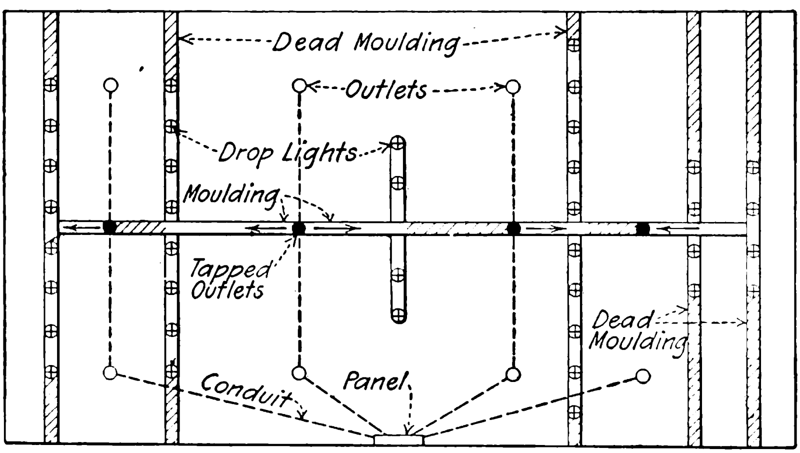


FIG. 106.—Molding wiring on fireproof ceiling.

for the canopy and the wires can be carried through the block eliminating the necessity of cutting the canopy.

134. **Wiring in approved metal molding** can be used for exposed work for circuits, where the difference of potential is not over 300 volts and where the power transmitted does not exceed 660 watts. Metal molding must be continuous from outlet to outlet, to junction

box or to approved fittings designed especially for use with metal molding. All outlets must be provided with approved terminal fittings which will protect the insulation of conductors from abrasion unless such protection is afforded by the construction of the boxes or fittings. Metal molding should not be used in damp places.

135. **Wire for Metal Molding.**—Single-braid, rubber-insulated wire is approved. In all cases wires must be laid in and not fished.

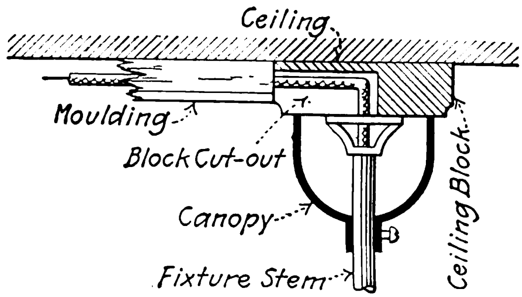


FIG. 107.—A molding-wiring fixture support

There is sufficient space in National Metal Molding for 4 No. 14 single-braid, rubber insulated wires. It is often necessary to insert this number at double-pole switch loops, etc. The two or more wires of an alternating-current circuit must be in the same molding and those of a direct-current circuit should be so that if a change is made to alternating-current reconstruction will not be necessary.

136. **National metal molding** is made by the National Metal Molding Company of Pittsburgh, Pa. It consists of channel

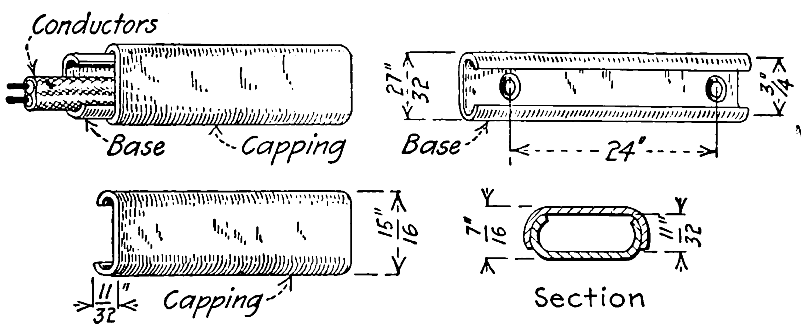


FIG. 108.—Dimensions of national metal molding.

capping that snaps over a channel base. The principal dimensions are given in Fig. 108. It is furnished in lengths of 8 ft. 6 in. It is Sherardized, a process whereby finely divided zinc is driven into the pores of the metal forming an iron-zinc alloy which is thoroughly rust-proof and which cannot be knocked off. Either water or oil paints adhere well to it. Because of the small space that it occupies it can be used to advantage on steel ceilings, in show-windows,

in show-cases and in other locations where appearance is a factor and where safety is essential.

137. **The application of national metal molding and fittings** is illustrated in Fig. 109, an imaginary lay-out shown to indicate how the material may be used.

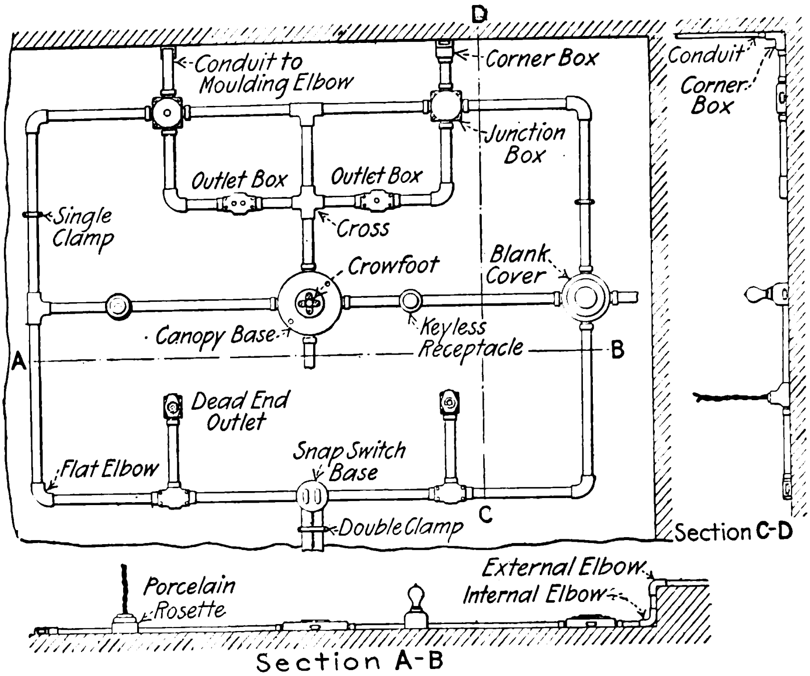


FIG. 109.—Application of metal molding and fittings.

138. **The cost of national metal molding** is $8.00 per 100 ft. list with a discount varying from 20 per cent. to 50 per cent. and with the point of delivery and the quantity purchased.

139. **The Cost of Metal Molding Fittings.**—The same discounts apply as those applying to molding. List prices for some are as follows: Cross, 17 cents each; base coupling, 2.5 cents; tee, 14 cents; elbows, internal, external and flat, 11 cents; outlet box, 20 cents; metal covers 5.5 cents; receptacles, 45 cents; bushings, 3.5 cents; snap switch bases, 25 cents; one-piece porcelain rosettes, 8 cents; two-piece porcelain rosettes, 25 cents.

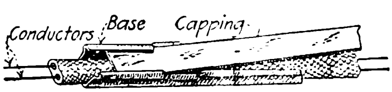


FIG. 110.—Lutz metal molding.

140. **Lutz metal molding** consists of a channel-shaped base and a strip of sheet metal that slips in, as illustrated in Fig. 110 which constitutes the capping. It is electro-galvanized and is furnished in 10 ft. lengths. Capping can be removed at either end or at any other point desired by making two hack-saw cuts with a fine-tooth (tubing) saw through the flanges of the base and slightly opening the cut portion to release the ends of the capping. It is

recommended that in making installations these hack-saw cuts be made at intervals to permit the future removal of the capping

141. **Fittings for Lutz molding** are made which are somewhat similar to those for the National. All fittings are arranged to insure electrical conductivity throughout the molding installation.

142. **Where metal molding passes through floors** it should be carried through an iron pipe extending from the ceiling below to a point 5 ft. above the floor, which will serve as an additional mechanical protection and exclude moisture. In residences, office buildings and similar locations where appearance is an essential feature, and where the mechanical strength of the molding itself is adequate, the iron pipe can extend from the ceiling below to a point 3 in. above the floor

143. **Metal molding must be grounded permanently** and effectively and so installed that adjacent lengths of molding will be mechanically and electrically secured at all points. It is essential

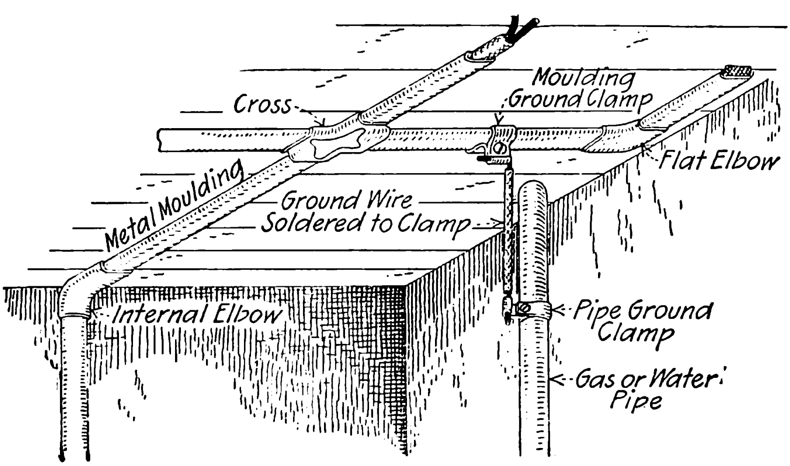


FIG. 110A.—Grounding metal molding.

that the metal of such systems be joined so as to afford electric conductivity sufficient to allow the largest fuse in the circuit to operate before a dangerous rise of temperature in the system can occur. Moldings and gas pipes must be securely fastened in metal outlet boxes, so as to secure good electrical connection. Where boxes used for centers of distribution do not afford good electrical connection the metal molding must be joined around them by suitable bond wires. Where sections are installed without being fastened to the metal structure of the building or grounded metal piping, they must be bonded together or joined to a permanent and effective ground connection.

The metal molding manufacturers provide fittings suitable for joining adjacent lengths of backing together and ground clamps (Fig 110, *A*) for grounding. Lapping the capping from one length to the adjacent one constitutes an electrical connection. Ground wires must be at least No. 10 B & S gage.

144. Installing National Metal Molding. *Separating.*—Reasonable care should be exercised in separating the backing and capping preparatory to installation. As the quickest, most satisfactory method, hooking one of the punched holes in the backing over a convenient nail or screw and drawing the capping off is recommended. *Cutting.*—Except in cases where the backing of the molding passes through under the fittings and is not cut, backing and capping should be cut before being separated in all cases. Because of the light stock, hack-saw blades having fine teeth and commonly known as "tube saws" should be used for cutting. Some construction men recommend marking deeply with a file and breaking. *Bending.*—The molding is readily bent and, with reasonable care, may be worked to any radius down to one of $4\frac{1}{2}$ in. Bends must be made in all cases before backing and capping are separated. *Supporting.*—The backing is punched and countersunk every 2 in. for the supporting screws or bolts. The support so afforded will usually be found more than ample, but further support may be secured either through additional punching with a special punch or by using a metal molding clamp. Fig. 111 shows a toggle bolt support for metal molding. When the metal molding is installed on uneven surfaces, such as the ceilings of old buildings, the capping has a tendency to spring away from the backing. This may be overcome by the use of two or three straps fastened over each length.

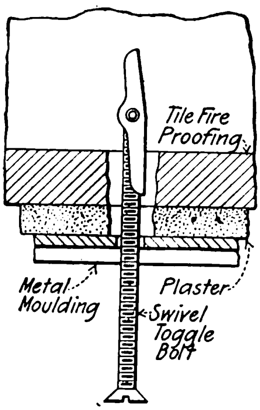


FIG. 111.—Toggle bolt being inserted.

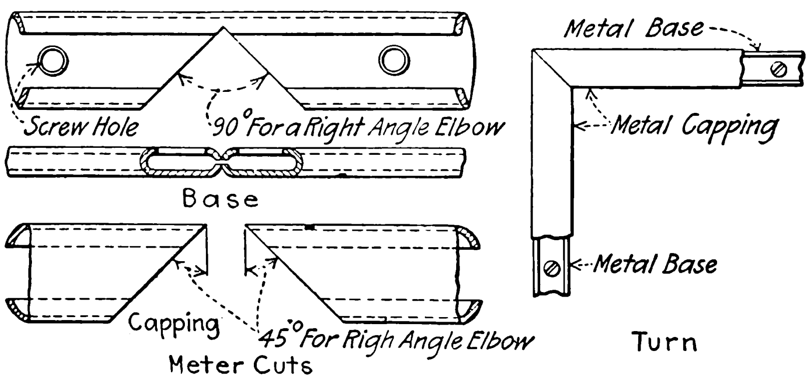


FIG. 112.—Mitered turn.

Loose Capping.—If the capping of the molding is loose, it should be removed from the backing and tightened by tapping it with a mallet or hammer at points about 8 in. apart but on one edge only.

145. Metal molding can be mitered for elbows and bends by cutting it with a hack-saw. Elbows and bends thus made have

the advantage that they fit into corners more closely than do the purchased fittings. Electrical conductivity is preserved by always leaving a portion of the backing intact. Fig. 112 shows how a turn can be made and Fig. 113 the method for an elbow.

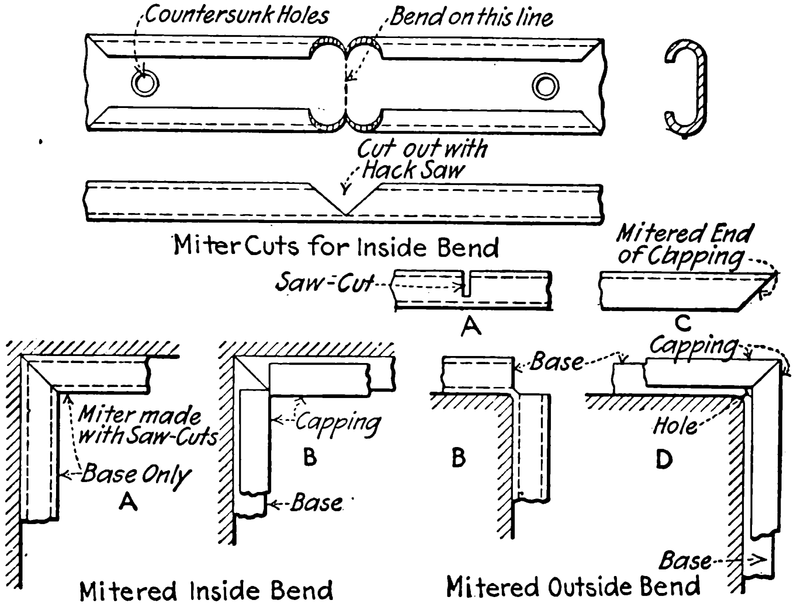


FIG. 113.—Mitered elbows.

KNOB-AND-TUBE WIRING

146. Concealed knob-and-tube wiring is used in frame houses where a low cost of installation is essential. The wires are concealed within floors and partitions. Concealed wiring can be installed cheaper by the knob-and-tube method than by any other (unless wooden moulding wiring be considered as concealed wiring), but the cost is greater than for open work on knobs and cleats. (Much of the matter on knob and tube wiring is from articles on this subject published in the *Pract. Eng.* commencing Sept. 1, 1912.)

147. The use of knob-and-tube work should be discouraged in so far as possible (Knox, *Electric Light Wiring*), as it is subject to mechanical injury and is liable to interference from rats and mice. The wires may sag against beams, laths, etc., or may be covered by shavings or other inflammable building material. Knob-and-tube work is prohibited by municipal ordinances in many cities and is being superseded by flexible steel and rigid iron conduit installations.

148. The wires are run just after the floors and studding are in place and before the lathing is done. This principal part of the work is called the "roughing in," and comprises the installation of the mains and the branches and the taps to the outlets. Frequently the basement wiring is not done until the building is

practically completed. The "finishing," which comprises the installation of the switches, fixtures, meter board, distributing panels, etc., is not usually done until the building is otherwise completed.

149. Wire and tie-wires for concealed knob-and-tube wiring must have an approved rubber insulation, but may be single-braid. Tie-wires should have an insulation equal to that of the conductors they support, and must not be smaller than No. 14. (Tie wires are not permitted for conductors smaller than No. 8. B. & S. gage. Where conductiors smaller than No. 8 are used they must be supported on split knobs except at the ends of runs where solid knobs should be used.)

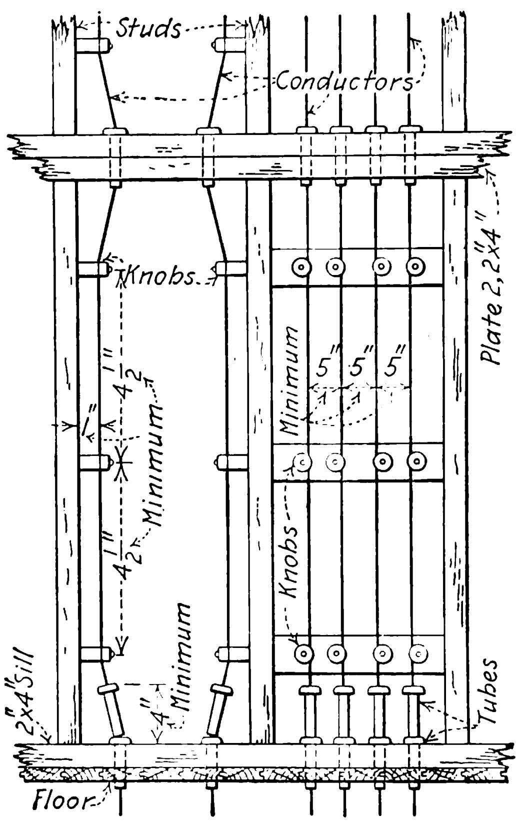


FIG. 114.—Knob-and-tube vertical run.

150. In making joints and splices in concealed knob-and-tube work, a serving of rubber tape and then one of friction tape are made around the splice. Inasmuch as most of the joints are inaccessible after the completion of the building, they should be very carefully made.

151. Wires must be supported in knob-and-tube wiring by approved porcelain knobs, which separate the wires at least 1 in. from the surface wired over. The wires must be maintained at least 5 in. apart, and when possible should be run (Fig. 114) on separate timbers and studding. Knobs are located at least every $4\frac{1}{2}$ ft. where the wire run is parallel to the supporting timber. Where it is impossible to maintain the 5 in. separation, the wires can be run closer together, provided each is encased in a continuous length of flexible tubing, or as it is often termed, "loom." When passing through floors, walls, etc., the wires must be protected by glass or porcelain tubes, as outlined in Fig. 114. Flexible tubing may in dry places be used to insulate the wires where projecting members of the building interfere with them. Porcelain tubes should be used where the wires cross each other or cross pipes (Fig. 115).

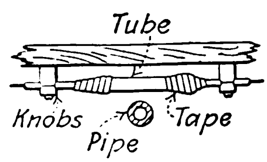


FIG. 115.—Wire crossing pipe.

152. Where circuits cannot be supported on porcelain or glass, in knob-and-tube work, approved metal conduit or approved armored cable must be used, except that for voltages of less than 300, where the wires are not exposed to moisture, they may be fished from outlet to outlet on the loop system if each is encased throughout in continuous lengths of approved flexible tubing.

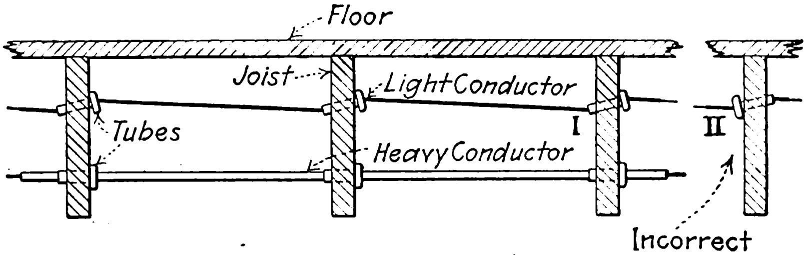


FIG. 116.—Wires through joists in tubes.

153. In wiring in thin partitions where there will not be at least 1 in. clear space between the surface of the wires and the plaster that oozes between the laths, the wires must be encased in loom (flexible conduit). This construction is required in the so-called 2 in. partitions.

154. Knobs for knob-and-tube work are of either the solid type (Fig. 8B and Table **16D**), or of the split type (Fig. 8A). Split knobs are required for conductors smaller than No. 8, except at the ends of runs. Solid knobs are permitted only when used to take the strain from the circuit wires—at the ends of runs and to

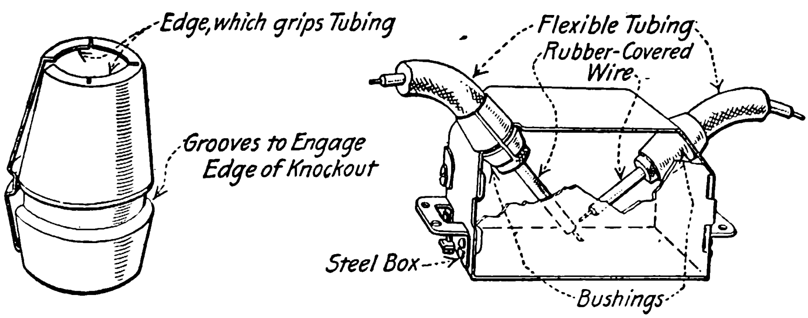


FIG. 116A.—Bushing for flexible tubing.

support outlets. The knob must provide at least a 1-in. separation from the surface wired over. See **16A** for further information about knobs.

155. Porcelain tubes provide insulation where the wires are carried through joists. (See **16F** for further information on tubes.) The holes for the tubes should (Fig. 116) preferably be slightly smaller than the tubes, so that the tubes when driven home with

a block of wood will stay in place. The holes for tubes for small wires should be pitched as this tends to retain the tubes in position in the timber. A long bit, the shank of which when in use rests on the joist next to the one being bored, is the best tool for boring pitched, tube holes. Tubes should always be so placed in pitched holes that their enlarged ends will be at the top, as a (Fig. 116, *I*), which will prevent their falling through. Never place tubes as at *II*, because when the wire loosens, as it will in old installations, they will fall out. For heavy conductors the tube holes should be bored with a beam-boring machine, at right angles to the beam. If they are not, it is difficult to pull in the wire and tube breakages will result. About 10 per cent. more wire is required where conductors are "zigzagged" through timbers than when they are carried straight through.

156. Porcelain tubes must be used on wires at the bottoms of plastered partitions (Fig. 114), an additional tube being placed where the wires pass through the sill or floor to protect from plaster droppings. The tubes must extend to at least 4 in. above the timber. Knobs must be so arranged that no strain that might tend to break them can come on tubes. Fig. 115 shows how a wire crossing a pipe should be protected by a procelain tube.

157. Flexible tubing must be used at all knob-and-tube work outlets to encase each wire. (See **16K** for properties of flexible tubing.) It should be used at distributing center, switch, fixture and similar outlets, and at all points where the wires cannot be separated from one another or from the surface wired over the distances specified for unprotected wire. The flexible tubing or loom must encase each wire from the last porcelain support (knob or tube), to 1 in. below the outlet, or with combination fixtures, to a point opposite the gas cap. The tubing must be firmly secured in position in outlet and switch boxes by some approved device that may or may not be a part of the box. See Fig. 116A for a flexible tubing bushing designed for this purpose.

The bushing shown in Fig. 116A grips the tubing and the pressure of the "knockout" holds the bushing securely to the tubing. The bushing is installed by slipping it over the tubing to the desired position and then forcing it into the "knockout" in the outlet or switch box. Not only does the bushing hold the tubing in place but it fills the space around the tubing, thus preventing the entrance into the box of plaster and dirt.

158. Fixture outlets are shown in Figs. 117 and 118. For an electric fixture a cleat, a piece of board at least $\frac{7}{8}$ in. thick (Fig. 117), into which the wood screws supporting the electrolier can turn, should be nailed between the joists or studs. Holes are bored through the cleat, through which the loom can pass. With a combination fixture (gas and electric) (Fig. 118) no cleat is necessary, because the gas pipe supports the fixture. The loom should be wired—iron wire will do—to the gas pipe, to prevent displacement by artisans that have occasion to work around the outlet.

159. In wiring for switches, loom must be used on the conductor ends from the last porcelain support, (Figs. 119, 120 and

121), the same as on conductor ends for other outlets. A pressed steel switch box (Fig. 122), should be used to encase each flush switch mechanism, even though it already be encased in porcelain. A $\frac{7}{8}$ in. wood cleat or cleats are arranged to support the switch

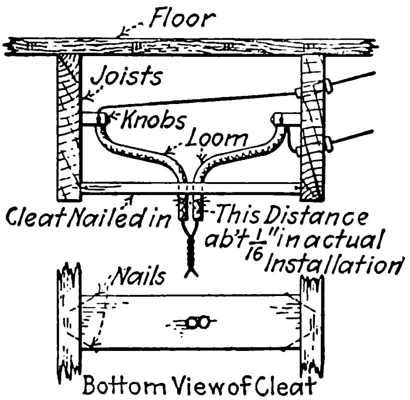


FIG. 117.—Outfit for an electric fixture.

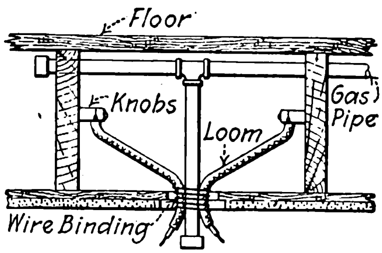


FIG. 118.—Loom protection at combination fixture outlet.

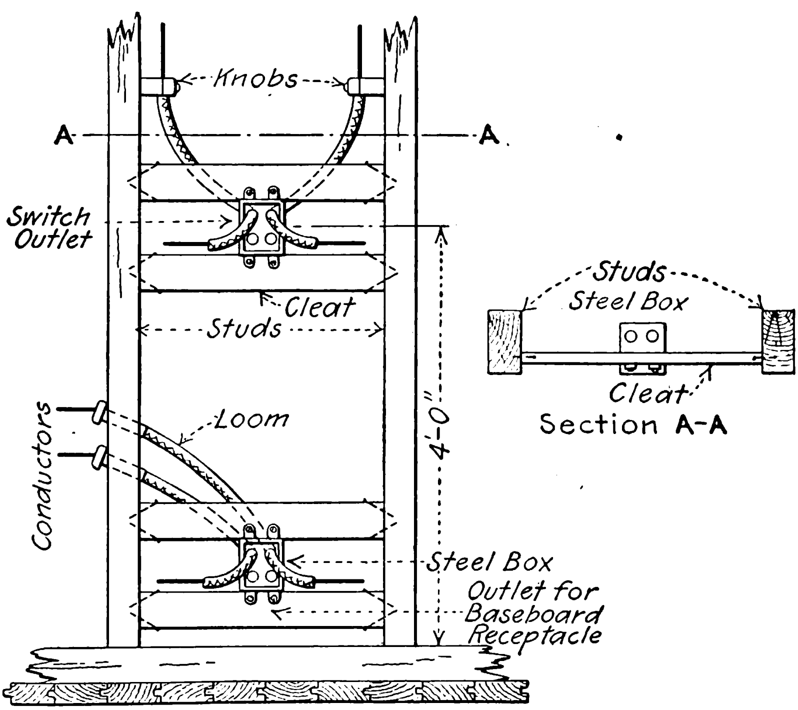


FIG. 119.—Switch and receptacle outlets.

box. These wooden cleats should not be set out flush with the outer edges of the studs, but should be set about $\frac{3}{8}$ in. back, as illustrated, to allow a space in which the plaster can take a "grip." (See Fig. 121.) For a surface snap switch outlet (Fig. 121), an

iron box is not necessary, but a $\frac{7}{8}$-in. cleat must be installed to hold the loom in place and to provide a proper support for the screws that hold the switch. In wiring old buildings, where supporting cleats were not originally provided back of the plaster, a $\frac{3}{4}$ in. wooden block or plate should be installed on the surface, to which the switch can be attached.

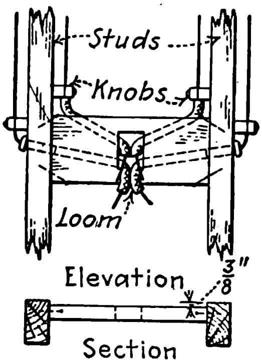


FIG. 120.—Arrangement of switch outlet wiring.

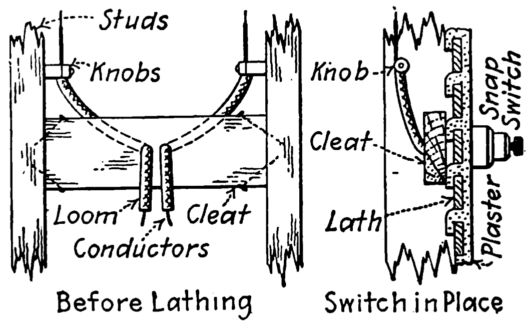


FIG. 121.—Surface switch wiring.

160. Steel switch boxes for knob-and-tube work, flush switches are formed from sheet steel, as shown in Fig. 122. A single-switch box can be expanded into one for any number of switches by using the proper number of spacers. Single- and double-switch boxes can be supplied already assembled and are used where feasible, because it is cheaper to buy them this way than to assemble them on the job. Holes partially punched, which can be knocked out

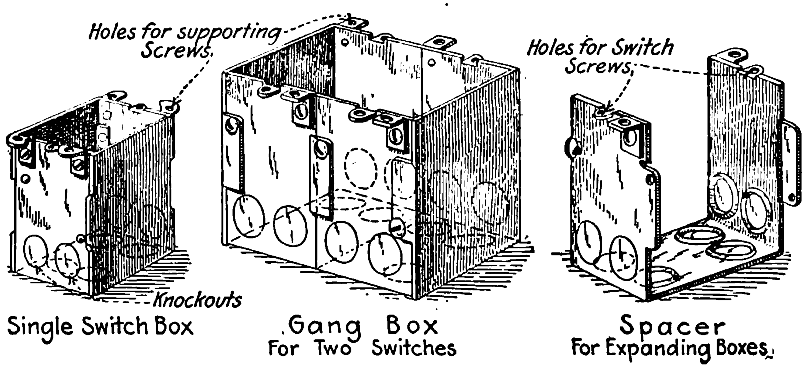


FIG. 122.—Switch box for knob-and-tube wiring.

with a hammer blow, are provided in the sides and back through which the flexible conduit wire protection can be extended. Boxes can be purchased which are adaptable for either knob-and-tube (flexible conduit or loom) or wrought-iron conduit work. Boxes which have adjustable supporting lugs, so the box can be moved in and out in relation to them to provide for adjustment to the surface of the plaster, are preferable. (See also 190 under "Conduit Wiring" for further information on steel switch boxes.)

CONDUIT WIRING

161. **There are two classes of conduit wiring,** rigid or iron conduit wiring, and flexible metal conduit wiring. Although steel-armored conductor wiring is not truly conduit wiring it is usually treated in the conduit wiring group and is so described in this book. (The material that follows on Conduit Wiring is largely from a series of articles on the subject written by the compiler of this book and printed, under the pen name of O. N. Casey, in *The Practical Engineer* commencing with the March 1, 1913 issue.)

162. **Rigid iron conduit wiring** is approved for both exposed and concealed work and for use in nearly all classes of buildings. For ordinary conditions wiring in iron conduit is probably the best although it is the most expensive. The advantages of iron conduits are: (1) It is fire-proof; (2) it is moisture-proof; (3) it is strong enough mechanically so that nails cannot be driven through it and so that it is not readily deformed by blows or by wheel-barrows being run over it; (4) it successfully resists the normal action of cement when imbedded in partitions or walls of fire-proof buildings.

163. **Lined and unlined iron conduit** can be obtained. The lined conduit is merely ordinary conduit lined with a paper tube that is treated with an insulating water-proof compound. The lining is cemented to the interior of the conduit by the compound.

164. **The advantages of unlined conduit** over lined conduit are (*Electric Light Wiring, Knox.*): (1) It is cheaper because it has no lining. A smaller size conduit can be used for conductors of a given size; (2) it is cheaper to install, as it can be bent, threaded and cut more readily than can lined conduit; (3) it is easier to draw wires into and out of unlined conduit than into and out of lined conduit; (4) in lined conduit in hot places the conductors sometimes stick to the lining which prevents their withdrawal.

165. **The disadvantages of unlined conduit** are (*Electric Light Wiring, Knox.*): (1) The unlined iron conduit may rust through due to the combined action of water or steam and the chemical elements in ash or other cements; (2) double-braided conductors must be used in unlined conduit to satisfy code rules. The increase in cost due to this requirement is slight as compared with the greater cost of lined conduit and the cost of installing it.

166. **Lined conduit is very seldom used now.** It sometimes finds application where every precaution must be taken to protect against trouble that might occur if the outer iron tube rusted through.

167. **Galvanized iron conduit** should be used if conduit is installed out of doors or in damp places or where it is imbedded in cement.

168. **When to use Iron Conduit Wiring.**—As a general proposition, conduit wiring should be used whenever the job will stand the cost. Ordinances of some cities now require that all

concealed wiring shall be in iron conduit. It is probable that the method will, because of its inherent advantages, grow in popularity and will ultimately be almost universally used. Iron conduit protects the conductors it contains and provides a smooth race-way permitting ready insertion or removal.

169. **Use of Iron Pipe in Place of Conduit.**—Electrical conduit is merely commercial standard-weight wrought-iron pipe that has been carefully reamed inside to remove burrs and then treated with zinc, or an enamel, baked on, to prevent rust. The threads on the ends of conduit lengths are standard pipe threads. Hence, where underwriters' inspectors do not have jurisdiction iron pipe can be used instead of conduit. The pipe is cheaper, and in dry locations it appears to serve as well as conduit. A coat of black stove-pipe enamel on the outside of the pipe will give it a finished appearance, and more than a superficial inspection is required to distinguish a pipe so treated from conduit. It is the practice in some plants where the buildings are fire-proof and where no insurance is carried to use galvanized iron pipe instead of conduit.

170. **Wire for use in unlined wrought-iron conduit** must be rubber-covered except in permanently dry, hot locations where slow-burning insulation may be permitted. Single-braid wire is permitted for conductors smaller than No. 6. Conductors No. 6 and larger should be double-braid. Duplex or multiple conductor cables must be double braid. Each conductor must be continuous from outlet to outlet without splices or taps. The same conduit can contain as many as four 2-wire or three 3-wire circuits of the same system. The same conduit must never contain circuits of different systems. Duplex wire (see Sect. I) particularly No. 14 is largely used for branch circuits in conduit wiring. Solid wire is used for conductors up to and including No. 8 or No. 6. Larger conductors should be stranded so that they can be readily pulled into the ducts.

171. **Where alternating-current circuits** are in conduit, all of the wires (two wires for a single-phase, three wires for a three-wire or three-phase and three or four wires for a two-phase circuit) of the circuit must be carried in the same conduit to prevent inductive voltage drop and dangerous overheating of the conduit.

172. **Table 173 of Conduit, Elbows and Couplings.**—Electrical conduit is merely standard-weight wrought-iron pipe, enameled, Sherardized or galvanized. The diameters are given in decimals, common fractions and sixty-fourths for convenience, because there are times when the values are needed expressed in each of these ways. When figuring wire and wire insulation diameters, all values are usually expressed in sixty-fourths which makes the sixty-fourths columns very valuable for ready reference. The weight columns are convenient for estimating transportation charges, and from the values in the list price columns, the cost of the materials can be obtained by applying the discount that one receives. As an estimating discount 50 per cent. can be safely used. Dimensions of elbows and couplings are often used in laying out work on the drawing-board or in cases where clearances must be estimated in advance. Table 185 gives the dimensions of standard conduit threads.

173. Unlined Wrought-iron Electrical Conduit, Elbows and Couplings

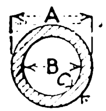


FIG. 123.—Section of conduit.

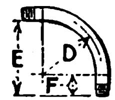


FIG. 124.—Conduit elbow.

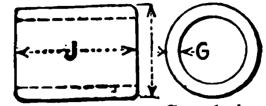


FIG. 125.—Conduit coupling.

Nominal size	Conduit											Elbows					Couplings				
	A Outside diameter.			B Inside diameter.			C Thickness of walls					D	E			F	I	J	G		
	Actual	Fractional in. to 64ths.	In 64ths to nearest 64th.	Nominal	Fractional in. to 64ths.	In 64ths to nearest 64th.	Nominal	Fractional in. to 64ths.	64 ths to nearest 64ths.	Nominal weight lb. per ft.	List price per 100 ft.	Radius of ϕ in.	Offset ins.	Weight, lb. of 100	List price, per 100	Length, straight portion	Outside diam.	Length	Thickness	Weight of 100 in lb.	List price, per 100
$\frac{1}{2}$	0.84	$\frac{27}{32}$	$\frac{54}{64}$	0.623	$\frac{5}{8}$	$\frac{40}{64}$	0.109	$\frac{3}{32}$	$\frac{6}{64}$	0.85	$ 8.50	$4\frac{1}{2}$	$7\frac{1}{2}$	73	$19.00	$2\frac{9}{16}$	$1\frac{3}{32}$	$1\frac{5}{16}$	$\frac{1}{4}$	$15\frac{1}{2}$	$ 7.00
$\frac{3}{4}$	1.05	$1\frac{1}{16}$	$\frac{68}{64}$	0.824	$\frac{53}{64}$	$\frac{53}{64}$	0.113	$\frac{7}{64}$	$\frac{7}{64}$	1.12	11.50	$5\frac{3}{8}$	$9\frac{1}{4}$	132	25.00	$3\frac{1}{4}$	$1\frac{11}{32}$	$1\frac{9}{16}$	$\frac{19}{64}$	$25\frac{1}{2}$	10.00
1	1.315	$1\frac{21}{64}$	$\frac{84}{64}$	1.048	$1\frac{3}{64}$	$\frac{67}{64}$	0.134	$\frac{1}{8}$	$\frac{8}{64}$	1.67	17.00	$5\frac{3}{4}$	$10\frac{1}{8}$	200	37.00	$4\frac{5}{8}$	$1\frac{21}{32}$	$1\frac{3}{4}$	$\frac{11}{32}$	$40\frac{1}{2}$	13.00
$1\frac{1}{4}$	1.66	$1\frac{42}{64}$	$\frac{106}{64}$	1.380	$1\frac{34}{64}$	$\frac{88}{64}$	0.140	$\frac{9}{64}$	$\frac{9}{64}$	2.24	23.00	$7\frac{1}{4}$	$11\frac{1}{2}$	300	45.00	$3\frac{7}{16}$	2	$1\frac{15}{16}$	$\frac{11}{32}$	$57\frac{1}{2}$	17.00
$1\frac{1}{2}$	1.90	$1\frac{29}{32}$	$\frac{122}{64}$	1.611	$1\frac{39}{64}$	$\frac{103}{64}$	0.145	$\frac{9}{64}$	$\frac{9}{64}$	2.68	27.50	$8\frac{1}{2}$	$12\frac{5}{8}$	415	60.00	$3\frac{3}{16}$	$2\frac{9}{32}$	$2\frac{3}{16}$	$\frac{3}{8}$	$71\frac{1}{4}$	21.00
2	2.375	$2\frac{3}{8}$	$\frac{132}{64}$	2.067	$2\frac{1}{16}$	$\frac{132}{64}$	0.154	$\frac{5}{32}$	$\frac{10}{64}$	3.61	37.00	$9\frac{1}{2}$	$15\frac{1}{4}$	700	110.00	$4\frac{9}{16}$	$2\frac{27}{32}$	$2\frac{5}{16}$	$\frac{15}{32}$	132	28.00
$2\frac{1}{2}$	2.875	$2\frac{7}{8}$	$\frac{184}{64}$	2.468	$2\frac{15}{32}$	$\frac{138}{64}$	0.204	$\frac{13}{64}$	$\frac{13}{64}$	5.94	58.50	$10\frac{1}{2}$	$17\frac{3}{4}$	1,138	180.00	$5\frac{13}{16}$	$3\frac{9}{32}$	$2\frac{11}{16}$	$\frac{17}{32}$	185	40.00
3	3.50	$3\frac{1}{2}$	$\frac{224}{64}$	3.067	$3\frac{1}{16}$	$\frac{196}{64}$	0.217	$\frac{7}{32}$	$\frac{14}{64}$	7.54	76.50	13	$19\frac{3}{8}$	1,885	480.00	$4\frac{5}{8}$	$4\frac{1}{64}$	3	$\frac{33}{64}$	300	60.00
$3\frac{1}{2}$	4.00	4	$\frac{256}{64}$	3.548	$3\frac{35}{64}$	$\frac{227}{64}$	0.266	$\frac{7}{32}$	$\frac{14}{64}$	9.00	92.00	15	21	2,100	1060.00	4	$4\frac{1}{2}$	$2\frac{1}{8}$	$\frac{1}{2}$	400	80.00
4	4.50	$4\frac{1}{2}$	$\frac{288}{64}$	4.026	$4\frac{1}{32}$	$\frac{258}{64}$	0.237	$\frac{15}{64}$	$\frac{15}{64}$	10.66	109.00	16	$22\frac{1}{2}$	2,160	1225.00	$4\frac{1}{4}$	$5\frac{3}{32}$	$3\frac{1}{8}$	$\frac{1}{2}$	412	100.00

All tubes 10 ft. long, threaded, both ends with coupling.

Price list in effect Aug. 1, 1913.

174. Table 178 of conduit bushing dimensions, gives values which are helpful when laying out conduit holes in outlets or panel boxes. Clearances can be provided and holes can be so disposed that the bushings will have ample turning room. The dimensions in the table were taken from samples.

175. Table 179 of conduit nipple dimensions is, since the function of the nipple is about the same as that of the bushing, used for the same purposes as the bushing table. The nipple screws into a coupling (see Table 181), while the bushing screws onto the threaded end of a length of conduit. The nipple is more compact than the bushing, hence is preferable for some work.

176. Punched steel lock-nuts are shown in Table 180. Lock-nuts are used on conduit on the outside of the box wherever the conduit enters an outlet-box, and their dimensions must often be known in laying out panel or outlet boxes, so that proper turning clearances can be provided for the nuts.

177. Galvanized iron pipe straps (Table 183), are used for supporting conduit to surfaces. The dimensions in the table are valuable, when laying out multiple conduit runs, to determine the spacings necessary between the conduits to allow for proper placing of the straps. The screw hole dimensions enable one to order in advance screws of the proper diameters to support the straps. Unfortunately, there are no standard dimensions in use by all the manufacturers of pipe straps, and those furnished by different makers will vary somewhat in size. The dimensions given are from one manufacturer's line, and are typical.

178. Malleable-iron Conduit Bushings

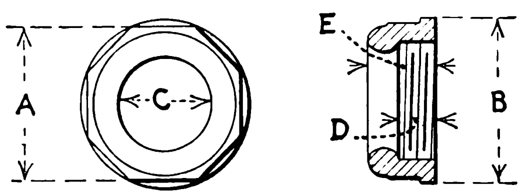


FIG. 126.—Conduit bushing.

Nominal size of conduit	A	B	C	D	E
3/8	15/32	27/32	25/32	3/16	11/32
1/2	19/32	1 1/32	15/16	1/4	13/32
3/4	3/4	1 1/4	1 5/32	1/4	15/32
1	31/32	1 17/32	1 13/32	5/16	17/32
1 1/4	1 5/16	1 29/32	1 11/16	3/8	19/32
1 1/2	1 17/32	2 5/32	1 31/32	13/32	5/8
2	1 15/16	2 11/16	2 15/32	13/32	21/32
2 1/2	2 11/32	3 5/32	2 7/8	15/32	3/4
3	2 27/32	3 25/32	3 17/32	17/32	7/8

179. Conduit Nipples

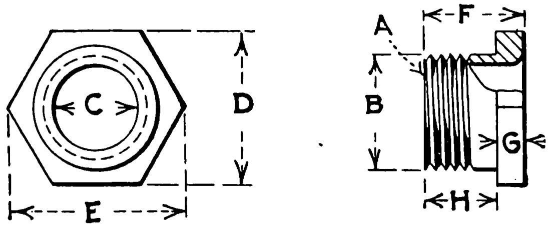


FIG. 127.—Conduit nipple.

Size of conduit	A Threads per inch	B Diameter of threads	C	D	E	F	G	H
½	14.0	0.82	0.62	1.00	1.15	0.62	0.12	0.50
¾	14.0	1.02	0.82	1.25	1.44	0.81	0.19	0.62
1	11.5	1.28	1.04	1.37	1.59	0.94	0.25	0.69
1¼	11.5	1.63	1.38	1.75	2.02	1.06	0.25	0.81
1½	11.5	1.87	1.61	2.00	2.31	1.12	0.31	0.81
2	11.5	2.34	2.06	2.50	2.89	1.31	0.31	1.00
2½	8.0	2.82	2.46	3.00	3.46	1.44	0.37	1.06
3	8.0	3.44	3.06	3.75	4.33	1.50	0.37	1.12
3½	8.0	3.94	3.54	4.25	4.91	1.62	0.44	1.19

180. Punched Steel Conduit Lock-nuts

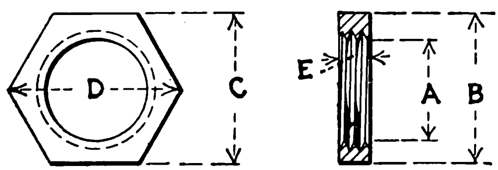


FIG. 128.—Conduit lock-nut.

Nominal size of conduit	Threads per in.	A	B	C	D	E
⅜	18	0.568	0.658	1	1⅛	3/16
				oct. hex.	oct. hex.	oct. hex.
½	14	0.701	0.815	1–1 1/16	1 1/16–1 7/32	5/32–⅛
¾	14	0.911	1.025	1¼	1 7/16	5/32
1	11½	1.144	1.283	1½	1 23/32	3/16
1¼	11½	1.488	1.627	2 1/32	2 5/16	3/16
1½	11½	1.727	1.866	2¼	2 9/16	3/16
2	11½	2.223	2.339	2 23/32	3⅛	7/32
2½	8	2.620	2.820	3¼	3¾	¼
3*	8	3.241	3.441	4 11/32–3 11/16	4 11/16–4	11/32–17/32

* The 3 in. lock-nut is octagonal instead of hexagonal.

181. Spacings for Conduit with Given Clearances

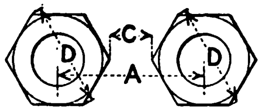


Fig. 129.—End View.

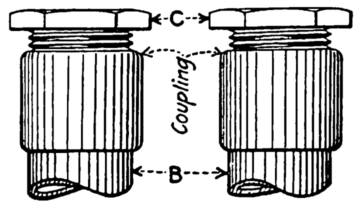


Fig. 130.—Elevation.

C = 1/8 in.

Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
1/2	A	1 1/4	1 3/8	1 1/2	1 11/16	1 13/16	2 1/8	2 7/16	2 3/4	3 1/3
	B	.41	.43	.42	.43	.44	.52	.58	.58	.70
3/4	A	1 3/8	1 1/2	1 5/8	1 13/16	1 15/16	2 1/4	2 9/16	3	3 1/4
	B	.43	.45	.44	.45	.46	.54	.60	.60	.72
1	A	1 1/2	1 5/8	1 3/4	1 15/16	2 1/16	2 3/8	2 11/16	3	3 3/8
	B	.43	.45	.44	.46	.46	.54	.60	.60	.72
1 1/4	A	1 11/16	1 13/16	1 15/16	2 1/8	2 1/4	2 9/16	2 7/8	3 1/4	3 3/16
	B	.43	.46	.46	.46	.47	.55	.62	.67	.74
1 1/2	A	1 13/16	1 15/16	2 1/16	2 1/4	2 3/8	2 1/16	3	3 3/8	3 11/16
	B	.44	.46	.46	.47	.47	.56	.62	.67	.74
2	A	2 1/8	2 1/4	2 3/8	2 3/16	2 11/16	3	3 5/16	3 5/8	4
	B	.52	.54	.53	.55	.56	.63	.63	.69	.82
2 1/2	A	2 7/16	2 9/16	2 11/16	2 7/8	3	3 5/16	3 5/8	3 15/16	4 5/16
	B	.58	.60	.60	.61	.62	.69	.76	.76	.89
3	A	2 3/4	3	3	3 1/4	3 3/8	3 5/8	3 15/16	4 7/16	4 3/4
	B	.58	.60	.60	.67	.67	.69	.74	.94	1.00
3 1/2	A	3 1/8	3 1/4	3 3/8	3 9/16	3 11/16	4	4 5/16	4 3/4	5
	B	.70	.72	.73	.74	.74	.82	.89	1.00	1.00

C = 3/8 in.

Size conduit		1/2	3/4	1	1 1/4
1/2	A	1 1/2	1 5/8	1 3/4	1 15/16
	B	.66	.68	.67	68
3/4	A	1 5/8	1 3/4	1 7/8	2 1/16
	B	.68	.70	.69	.71
1	A	1 3/4	1 7/8	2	2 3/16
	B	.68	.69	.69	.71
1 1/4	A	1 15/16	2 1/16	2 3/16	2 3/8
	B	.68	.71	.71	.71
1 1/2	A	2 1/16	2 3/16	2 5/16	2 1/2
	B	.69	.71	.71	.72
2	A	2 3/8	2 1/2	2 5/8	2 13/16
	B	.77	.79	.78	.80
2 1/2	A	2 11/16	2 13/16	2 15/16	3 1/8
	B	.83	.85	.85	.86
3	A	3	3 1/8	3 1/4	3 1/2
	B	.83	.85	.85	.92
3 1/2	A	3 3/8	3 1/2	3 5/8	3 13/16
	B	.96	.98	.98	.99

C = 1/4 in.

Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
1/2	A	1 3/8	1 1/2	1 5/8	1 13/16	1 15/16	2 1/4	2 9/16	2 7/8	3 1/4
	B	.53	.55	.54	.55	.56	.64	.70	.70	.83
3/4	A	1 1/2	1 5/8	1 3/4	1 15/16	2 1/16	2 3/8	2 11/16	3	3 3/8
	B	.55	.57	.56	.58	.58	.66	.72	.72	.86
1	A	1 3/8	1 3/4	1 7/8	2 1/16	2 3/16	2 1/2	2 13/16	3 1/8	3 1/2
	B	.55	.57	.56	.58	.58	.66	.72	.72	.85
1 1/4	A	1 13/16	1 15/16	2 1/16	2 1/4	2 3/8	2 11/16	3	3 3/8	3 11/16
	B	.55	.58	.58	.58	.59	.67	.73	.79	.86
1 1/2	A	1 15/16	2 1/16	2 3/16	2 3/8	2 1/2	2 13/16	3 1/8	3 1/2	3 13/16
	B	.56	.58	.58	.59	.59	.68	.74	.79	.87
2	A	2 1/4	2 3/8	2 1/2	2 11/16	2 13/16	3 1/8	3 7/16	3 3/4	4 1/8
	B	.64	.66	.65	.67	.68	.75	.81	.81	.94
2 1/2	A	2 9/16	2 11/16	2 13/16	3	3 1/8	3 7/16	3 3/4	4 1/16	4 7/16
	B	.70	.72	.72	.73	.74	.81	.87	.88	1.00
3	A	2 7/8	3	3 1/8	3 3/8	3 1/2	3 3/4	4 1/16	4 3/16	4 7/8
	B	.70	.72	.72	.79	.79	.81	.88	1.06	1.12
3 1/2	A	3 1/4	3 3/8	3 1/2	3 11/16	3 13/16	4 1/8	4 7/16	4 7/8	5 1/8
	B	.83	.86	.85	.86	.87	.94	1.00	1.12	1.12

C = 1/2 in.

Size conduit		1/2	3/4	1	1 1/4
1/2	A	1 5/8	1 3/4	1 7/8	2 1/16
	B	.78	.80	.79	.80
3/4	A	1 3/4	1 7/8	2	2 3/16
	B	.80	.82	.81	.83
1	A	1 7/8	2	2 1/8	2 5/16
	B	.80	.81	.81	.83
1 1/4	A	2 1/16	2 3/16	2 5/16	2 1/2
	B	.80	.83	.83	.83
1 1/2	A	2 3/16	2 5/16	2 7/16	2 5/8
	B	.81	.83	.83	.84
2	A	2 1/2	2 5/8	2 3/4	2 15/16
	B	.89	.91	.90	.92
2 1/2	A	2 13/16	2 15/16	3 1/16	3 1/4
	B	.95	.97	.97	.98
3	A	3 1/8	3 1/4	3 3/8	3 5/8
	B	.95	.97	.97	1.04
3 1/2	A	3 1/2	3 5/8	3 3/4	3 15/16
	B	1.01	1.04	1.03	1.04

181. Spacings for Conduit with Given Clearances (*Continued*)

D in nearest practical dimension			
Conduit	D	Conduit	D
1/2	1 1/8	2	2 7/8
3/4	1 3/8	2 1/2	3 1/2
1	1 5/8	3	4 5/16
1 1/4	2	3 1/2	4 7/8
1 1/2	2 1/4	....	....

C = 3/8 in.

1 1/2	2	2 1/2	3	3 1/2
2 1/16	2 3/8	2 11/16	3	3 3/8
.69	.77	.83	.83	.96
2 3/16	2 1/2	2 13/16	3 1/8	3 1/2
.71	.79	.85	.85	.98
2 5/16	2 5/8	2 15/16	3 1/4	3 5/8
.71	.78	.85	.85	.98
2 1/2	2 3/16	3 1/8	3 1/2	3 13/16
.72	.80	.87	.92	.99
2 5/8	2 15/16	3 1/4	3 5/8	3 15/16
.72	.81	.87	.92	.99
2 15/16	3 1/4	3 7/16	3 7/8	4 1/4
.81	.88	.88	.94	1.07
3 1/4	3 9/16	3 1/8	4 3/16	4 7/16
.87	.94	1.01	1.01	1.13
3 5/8	3 7/8	4 3/16	4 11/16	5
.92	.94	.99	.99	1.25
3 15/16	4 1/4	4 9/16	5	5 1/4
.99	1.07	1.13	1.25	1.25

C = 5/8 in.

Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
1/2	A	1 3/4	1 7/8	2	2 3/16	2 5/16	2 5/8	2 15/16	3 1/4	3 5/8
	B	.91	.93	.92	.93	.94	1.02	1.08	1.08	1.14
3/4	A	1 7/8	2	2 1/8	2 5/16	2 7/16	2 3/4	3 1/16	3 3/8	3 3/4
	B	.93	.95	.94	.96	.96	1.04	1.10	1.10	1.17
1	A	2	2 1/8	2 1/4	2 7/16	2 9/16	2 7/8	3 3/16	3 1/2	3 7/8
	B	.92	.94	.94	.96	.96	1.03	1.10	1.10	1.16
1 1/4	A	2 3/16	2 5/16	2 7/16	2 5/8	2 3/4	3 1/16	3 3/8	3 3/4	4 1/16
	B	.93	.96	.96	.96	.97	1.05	1.12	1.17	1.24
1 1/2	A	2 5/16	2 7/16	2 9/16	2 3/4	2 7/8	3 3/16	3 1/2	4	4 3/16
	B	.94	.96	.96	.97	.97	1.06	1.11	1.17	1.24
2	A	2 5/8	2 3/4	2 7/8	3 1/16	3 3/16	3 1/2	3 13/16	4 1/4	4 1/2
	B	1.02	1.04	1.03	1.05	1.05	1.13	1.13	1.19	1.32
2 1/2	A	2 15/16	3 1/16	3 3/16	3 3/8	3 1/2	3 13/16	4 1/8	4 1/2	4 13/16
	B	1.08	1.10	1.10	1.11	1.12	1.19	1.26	1.26	1.39
3	A	3 1/4	3 3/8	3 1/2	3 3/4	4	4 1/4	4 1/2	4 15/16	5 1/4
	B	1.08	1.10	1.10	1.17	1.17	1.19	1.24	1.24	1.44
3 1/2	A	3 5/8	3 3/4	3 7/8	4 1/16	4 3/16	4 1/4	4 13/16	5 1/4	5 1/2
	B	1.14	1.17	1.16	1.24	1.24	1.32	1.39	1.44	1.56

C = 1/2 in.

1 1/2	2	2 1/2	3	3 1/2
2 3/16	2 1/2	2 13/16	3 1/8	3 1/2
.81	.89	.95	.95	1.08
2 5/16	2 5/8	2 15/16	3 1/4	3 5/8
.83	.91	.97	.97	1.10
2 7/16	2 3/4	3 1/16	3 3/8	3 3/4
.83	.90	.97	.97	1.10
2 5/8	2 15/16	3 1/4	3 5/8	3 15/16
.84	.92	.99	1.04	1.11
2 3/4	3 1/16	3 3/8	3 3/4	4 1/16
.84	.93	.98	1.04	1.11
3 1/16	3 3/8	3 11/16	4	4 3/8
.93	1.00	1.00	1.06	1.20
3 3/8	3 11/16	4	4 5/16	4 11/16
.99	1.06	1.13	1.13	1.26
3 3/4	4	4 5/16	4 13/16	5 1/8
1.04	1.06	1.14	1.14	1.31
4 1/16	4 1/8	4 11/16	5 5/16	5 3/8
1.11	1.13	1.31	1.31	1.37

C = 3/4 in.

Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
1/2	A	1 7/8	2	2 1/8	2 5/16	2 7/16	2 3/4	3 1/16	3 3/8	3 3/4
	B	1.03	1.05	1.04	1.05	1.06	1.14	1.20	1.20	1.26
3/4	A	2	2 1/8	2 1/4	2 7/16	2 9/16	2 7/8	3 3/16	3 1/2	3 7/8
	B	1.05	1.07	1.06	1.08	1.08	1.16	1.22	1.22	1.29
1	A	2 1/8	2 1/4	2 3/8	2 9/16	2 11/16	3	3 5/16	3 5/8	4
	B	1.04	1.06	1.06	1.08	1.08	1.15	1.22	1:22	1.35
1 1/4	A	2 5/16	2 7/16	2 9/16	2 3/4	2 7/8	3 3/16	3 1/2	3 7/8	4 3/16
	B	1.05	1.08	1.08	1.08	1.09	1.17	1.24	1.29	1.36
1 1/2	A	2 7/16	2 9/16	2 11/16	2 7/8	3	3 5/16	3 5/8	4 1/8	4 5/16
	B	1.06	1.08	1.08	1.09	1.09	1.18	1.25	1.29	1.37
2	A	2 3/4	2 7/8	3	3 3/16	3 5/16	3 5/8	3 15/16	4 3/8	4 5/8
	B	1.14	1.16	1.15	1.17	1.18	1.25	1.25	1.31	1.45
2 1/2	A	3 1/16	3 3/16	3 5/16	3 1/2	3 5/8	3 15/16	4 1/4	4 5/8	4 15/16
	B	1.20	1.22	1.22	1.23	1.24	1.31	1.36	1.38	1.51
3	A	3 3/8	3 1/2	3 5/8	3 7/8	4 1/8	4 3/8	4 5/8	5 1/16	5 3/8
	B	1.20	1.22	1.22	1.29	1.29	1.31	1.45	1.36	1.56
3 1/2	A	3 3/4	3 7/8	4	4 3/16	4 5/16	4 3/8	4 15/16	5 3/8	5 5/8
	B	1.26	1.29	1.28	1.36	1.37	1.45	1.51	1.56	1.68

182. Table 181 of conduit spacings for different clearances between conduits and their lock-nuts, is exceedingly valuable to a man who is designing or erecting conduit work. From it he can determine directly just what the distance between centers of conduits should be for given clearances between nipples or conduit. This data is indispensable when laying out the centers of a row of holes through which conduit is to enter a panel box, or in laying out the supports for a multiple conduit run.

183. Galvanized Iron Pipe Straps

All dimensions are in inches

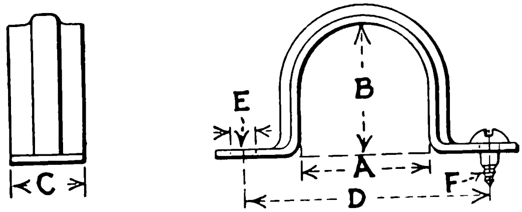


FIG. 131.—Pipe strap.

Nominal size of conduit	A Width of opening	B Height of opening	C Width of strap	D Distance between centers of screw holes	E Diameter of screw hole	F Size of wood screw to use	Approximate cost per 100	Approximate number per pound
						No. in.		
1/4	9/16	17/32	5/8	1 9/16	0.20	8 × 5/8	$0.40	75
3/8	11/16	21/32	5/8	1 3/8	0.20	8 × 3/4	0.45	72
1/2	7/8	25/32	5/8	1 5/8	0.20	8 × 3/4	0.50	40
3/4	1 1/8	1	3/4	2 1/8	0.22	10 × 3/4	0.75	29
1	1 3/8	1 11/32	3/4	2 3/8	0.22	10 × 7/8	1.00	21
1 1/4	1 3/4	1 5/8	13/16	2 3/4	0.22	10 × 1	1.25	18
1 1/2	2	1 7/8	13/16	3	0.22	10 × 1	1.50	14
2	2 1/2	2 5/16	1	3 3/4	0.22	10 × 1 1/4	2.00	12
2 1/2	2 3/4	2 15/16	7/8	4 3/8	0.25	11 × 1 1/4	2.75	6

184. That the conductors can be removed and replaced in conduit is one of the advantages of conduit wiring. If a size of conduit is selected that is too small for the wires, they will become wedged in, particularly in a warm location and withdrawal will be impossible.

184A. In selecting a conduit size for the conductors of a three-wire system with a neutral twice the size of the outer conductors, use a conduit of a size to take four wires the size of the outers. For example, the conduit for a three-wire main composed of 2–200,000 cir. mil outers and 1–400,000 cir. mil neutral should be large enough to accommodate 4–200,000 cir. mil conductors. The Underwriters (except by special permission) permit but four 2-wire circuits or three 3-wire circuits in one conduit. Circuits of different systems must never be carried in the same conduit.

185. Standard Conduit and Pipe Threads

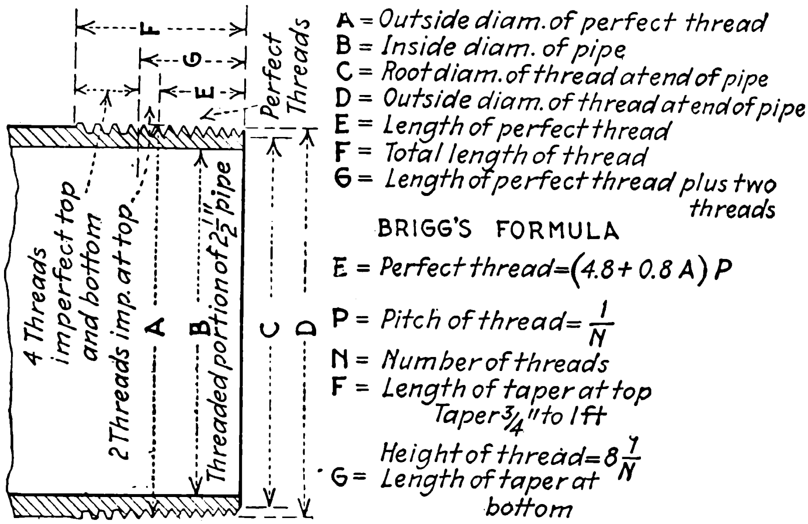


FIG. 132.—Standard conduit and pipe threads.

Size, pipe	No. of threads per in.	A	B	C	D	E	F	G	Diameter drill
1/8	27	0.405	0.270	0.334	0.393	0.19	0.41	0.264	21/64
1/4	18	0.540	0.364	0.433	0.522	0.29	0.62	0.402	7/16
3/8	18	0.675	0.494	0.567	0.656	0.30	0.63	0.408	9/16
1/2	14	0.840	0.623	0.702	0.816	0.39	0.82	0.534	11/16
3/4	14	1.050	0.824	0.911	1.025	0.40	0.83	0.546	29/32
1	11 1/2	1.315	1.048	1.144	1.283	0.51	1.03	0.683	1 5/32
1 1/4	11 1/2	1.660	1.380	1.488	1.627	0.53	1.06	0.707	1 15/32
1 1/2	11 1/2	1.900	1.611	1.727	1.866	0.55	1.07	0.724	1 23/32
2	11 1/2	2.375	2.067	2.200	2.339	0.58	1.10	0.757	2 7/32
2 1/2	8	2.875	2.468	2.618	2.818	0.89	1.64	1.138	2 5/8
3	8	3.500	3.067	3.243	3.443	0.95	1.70	1.200	3 1/4
3 1/2	8	4.000	3.548	3.738	3.938	1.00	1.75	1.250	3 23/64
4	8	4.500	4.026	4.233	4.443	1.05	1.80	1.300	4 1/4

186. Conduit Wire Capacity.—**187,** 188 and **188A**, which gives *Nat. Elec. Code* recommendations, show how many rubber-covered conductors can be pulled into standard, iron conduit (iron pipe sizes). Table 187 gives values for medium runs,—average runs as defined under Table 187. Where runs are short or have few turns smaller conduit can be used than for long runs with several sharp turns. Table 188 indicates about the minimum and maximum limits. Conduit smaller than ½ in. is not permitted for light or power wiring, but ⅜-in. conduit is used for signal work. No wire smaller than No. 14 is permitted for light or power, but smaller ones are used for signal work.

Conduit should always be large enough that great force will not be necessary to pull wires into it. Where too much force is used the insulation will be injured and the wires wedged so that they cannot be withdrawn. Conduit is too small if block-and-tackle must be used to pull in small- and medium-sized wire. Wire larger than No. 8 should be stranded.

187. Wire Capacity of Unlined, Wrought Iron Conduit—Medium Runs (See Par. 186)

	Size wire: American or B. & S. gage	Size wire: Circular mils	Safe carrying capacity, amp. Rubber insulation 1915 Code Rules	Diam. rubber insul. double braid. in 32ds in.	Size of unlined, wrought-iron conduit for 0–600 volts, rubber-insulated double-braid wires. Permissible number of wires in one conduit: 1	2	3	4	5	6	7	8	9	10	11, 12	13, 14	15, 16	17, 18	19	20, 21
Solid	18	1,624	3	6	3/8	3/8	3/8	1/2	3/4	3/4	3/4	3/4	3/4	1	1	1	1 1/4	1 1/4	1 1/4	1 1/4
Solid	16	2,583	6	7	3/8	3/8	1/2	1/2	3/4	3/4	3/4	1	1	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4
Solid	14	4,107	15	8	3/8	1/2	3/4	3/4	1	1	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	2
Solid	12	6,530	20	9	3/8	3/4	3/4	3/4	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	2	2	2
Solid	10	10,380	25	10	3/8	3/4	1	1	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	2	2	2	2
Solid	8	16,510	35	11	3/8	3/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	2	2	2	2	2 1/2	2 1/2
Stranded	6	26,250	50	14	1/2	1	1 1/4	1 1/4	1 1/2	1 1/2	1 1/2	2	2	2	2 1/2	2 1/2	2 1/2	3	3	3
Stranded	5	33,100	55	15	3/4	1 1/4	1 1/4	1 1/4	1 1/2	2	2	2	2 1/2	2 1/2	2 1/2	2 1/2	3	3	3	3
Stranded	4	41,740	70	16	3/4	1 1/4	1 1/4	1 1/2	1 1/2	2	2	2	2 1/2	2 1/2	2 1/2	3	3	3	3	3 1/2
Stranded	3	52,630	80	17	3/4	1 1/4	1 1/4	1 1/2	2	2	2	2 1/2	2 1/2	2 1/2	3	3	3	3 1/2	3 1/2	3 1/2
Stranded	2	66,370	90	19	3/4	1 1/2	1 1/2	2	2	2 1/2	2 1/2	2 1/2	3	3	3	3 1/2	3 1/2	4	4	4
Stranded	1	83,690	100	21	1	1 1/2	2	2	2 1/2	2 1/2	3	3	3	3	3 1/2	3 1/2	4	4	4 1/2	4 1/2
Stranded	0	105,500	125	23	1	2	2	2	2 1/2	3	3	3	3 1/2	3 1/2	3 1/2	4	4 1/2	4 1/2	5	5
Stranded	00	133,100	150	24	1	2	2	2 1/2	2 1/2	3	3	3	3 1/2	3 1/2	4	4	4 1/2	5	5	5
Stranded	000	167,800	175	26	1 1/4	2	2 1/2	2 1/2	3	3	3 1/2	3 1/2	3 1/2	4	4	4 1/2	5	5	6	6
Stranded	0000	211,600	225	28	1 1/4	2	2 1/2	3	3	3 1/2	3 1/2	3 1/2	4	4	4 1/2	5	5	6	6	6
	....	250,000	260	30	1 1/4	2 1/2	2 1/2	3	3 1/2	3 1/2	4	4	4 1/2	4 1/2	5	5	6	6	6......	
	....	300,000	275	32	1 1/2	2 1/2	3	3	3 1/2	4	4	4 1/2	4 1/2	5	5	6	6......		....	
	....	350,000	300	1″ 2	1 1/2	3	3	3 1/2	3 1/2	4	4 1/2	4 1/2	5	5	6	6	6......		....	
	....	400,000	325	1″ 3	1 1/2	3	3	3 1/2	4	4 1/2	4 1/2	4 1/2	5	5	6	6	....		....	
	....	450,000	360	1″ 5	1 1/2	3	3	3 1/2	4	4 1/2	4 1/2	5	5	6	6	6	....		....	

187. **Wire Capacity of Unlined, Wrought Iron Conduit—Medium Runs** (See Par. **186**) (*Continued*)

Stranded	500,000	400	1″	6	2	3	3½	3½	4	4½	5	5	6	6	6			
	550,000	450	1″	8	2	3	3½	4	4½	5	5	6	6	6				
	600,000	450	1″	9	2	3½	3½	4	4½	5	5	6	6	6				
	650,000	475	1″	11	2	3½	3½	4	4½	5	6	6	6	6				
	700,000	500	1″	12	2½	3½	4	4½	5	6	6	6	6					
	750,000	525	1″	13	2½	3½	4	4½	5	6	6	6						
	800,000	550	1″	14	2½	3½	4	4½	5	6	6	6						
	850,000	575	1″	15	2½	3½	4	4½	5	6	6	6						
	900,000	600	1″	16	2½	4	4	4½	5	6	6	6						
	950,000	625	1″	17	2½	4	4½	5	6	6	6							
	1,000,000	650	1″	18	2½	4	4½	5	6	6								
	1,100,000	690	1″	20	2½	4	4½	5	6	6								
	1,200,000	730	1″	22	2½	4½	5	5	6									
	1,300,000	770	1″	24	3	4½	5	6	6									
	1,400,000	810	1″	25	3	4½	5	6	6									
	1,500,000	850	1″	27	3	4½	5	6										
	1,600,000	890	1″	28	3	5	5	6										
	1,700,000	930	1″	30	3	5	6	6										
	1,800,000	970	1″	31	3	5	6	6										
	1,900,000	1,010	2″	1	3	5	6	6										
	2,000,000	1,050	2″	2	3	6	6											

Table of conduit sizes for No. 14 B. & S. duplex, double-braided cables for 0 to 600 volts

Size conduit	No. of duplex cables, ordinary runs
½	1
¾	2
1	3
1¼	6
1½	8
2	15

A **short run** is one that is not over 150 ft. in length and that is almost straight but it may have one or two bends of a radius not less than 3 ft. Good conditions for pulling and feeding wire are assumed.

A **medium run** is one that does not exceed 150 ft. in length and has not more than three or four easy bends. Or it may be 250 ft. long and nearly straight. Or it may be a short run with one close bend and one or two easy ones.

A **long run** is one of a length exceeding 150 ft. with close or medium bends: a run with more than one close bend, or any run with an extra close bend.

188. Wire Capacity of Unlined Wrought-iron Conduit for Short, Medium and Long Runs. (See Pars. 186 and 187.)

Size of wire			Size of conduit, inches							
			1 wire in conduit			2 wires in conduit			3 wires in conduit	
	B. & S. Gage	Circular mils	Short Run	Medium Run	Long Run	Short Run	Medium Run	Long Run	Short Run	Medium Run	Long Run
Solid	14	4,107	3/8	3/8	1/2	1/2	1/2	3/4	1/2	3/4	1
	12	6,530	3/8	3/8	1/2	1/2	3/4	3/4	3/4	3/4	1
	10	10,380	3/8	3/8	1/2	1/2	3/4	3/4	3/4	1	1
	8	16,510	3/8	3/8	1/2	3/4	3/4	1	1	1¼	1¼
Stranded	6	26,250	1/2	1/2	3/4	1	1	1¼	1	1¼	1¼
	4	41,740	1/2	3/4	3/4	1	1¼	1¼	1¼	1¼	1½
	3	52,630	1/2	3/4	3/4	1¼	1¼	1½	1¼	1¼	1½
	2	66,370	1/2	3/4	1	1¼	1½	1½	1¼	1½	2
	1	83,690	1/2	1	1	1¼	1½	2	1½	2	2
	0	105,500	3/4	1	1	1½	2	2	2	2	2
	00	133,100	1	1	1	1½	2	2	2	2	2
	000	167,800	1	1¼	1¼	2	2	2	2	2½	2½
	0000	211,600	1	1¼	1¼	2	2	2½	2	2½	3
	.....	300,000	1¼	1½	1½	2	2½	2½	2½	3	3
	.....	400,000	1½	1½	2	2½	3	3	3	3	3½
	.....	500,000	2	2	2½	3	3	3½	3½	3½	4
	.....	700,000	2	2½	2½	3	3½	4	4	4	4½
	.....	1,000,000	2	2½	3	4	4	4½	4½	4½	5
	.....	1,500,000	3	3	4	4½	4½	5	5	5	6
	.....	2,000,000	3	3	4	6	6	7	6	6	7

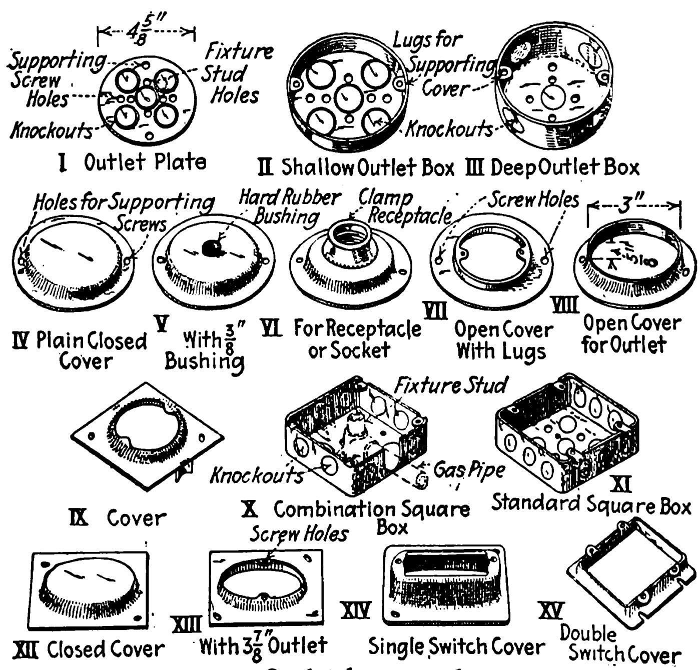


FIG. 133.—Outlet boxes and covers.

188A. Standard Code Sizes of Unlined Wrought-iron Conduit for Installation of Wire and Cables.—Conduit sizes based on the use of not more than three 90-degree elbows in runs taking up to and including No. 10 wire, and two elbows for wires larger than No. 10. Wires No. 8 and larger are stranded. Special permission is required of the inspection department having jurisdiction for the installation of more than nine wires in the same conduit. The wires used by the telephone companies of various cities differ as to thickness of insulation. The table "A" gives values satisfactory for both light and heavy insulation. For explanation of column heading reference letters for this table A, see footnotes. All data in following table from 1915 Nat. Elec. Code, except those in *italics* which are Nat. Elec. Contr's Ass'n recommendations.

Size of wire		Single wires				Twin or duplex wires			Three-wire convertible system		
B. & S. or A.W.G.	Circular mils	1 wire	2 wires	3 wires	4 wires	Size, A.W.G. or B. & S.	Number of wires	Size of conduit	Size of conductors, A.W.G. or B. & S. 2 conductors	1 conductor	Conduit size, in.
14	4,107	½	½	½	¾	14	1	½	14	10	¾
12	6,530	½	¾	¾	¾	14	2	¾	12	8	¾
10	10,380	½	¾	¾	1	14	3	1	10	6	1
8	16,510	½	1	1	1	14	4	1	8	4	1
6	26,250	½	1	1¼	1¼	12	1	½	6	2	1¼
5	33,100	¾	1¼	1¼	1¼	12	2	¾	5	1	1¼
4	41,740	¾	1¼	1¼	1½	12	3	1	4	0	1½
3	52,630	¾	1¼	1¼	1½	12	4	1¼	3	00	1½
2	66,370	¾	1¼	1½	1½	10	1	¾	2	000	1½
1	83,690	¾	1½	1½	2	10	2	1	1	0000	2
0	105,500	1	1½	2	2	10	3	1¼	0	250,000	2
00	133,100	1	2	2	2½	10	4	1¼	00	350,000	2½
000	167,800	1	2	2	2½				000	400,000	2½
0000	211,600	1¼	2	2½	2½				0000	550,000	3
	200,000	1¼	2	2½	2½				250,000	600,000	3
	250,000	1¼	2½	2½	3				300,000	800,000	3
	300,000	1¼	2½	2½	3				400,000	1,000,000	3½
	400,000	1¼	3	3	3½				500,000	1,250,000	4
	500,000	1½	3	3	3½				600,000	1,500,000	4
	600,000	1½	3	3½	..				700,000	1,750,000	4½
	700,000	2	3½	3½	..				800,000	2,000,000	4½
	800,000	2	3½	4	..				......	....	....
	900,000	2	3½	4	..				......	....	....
	1,000,000	2	4	4	..				......	....	....
	1,250,000	2½	4½	4½	..						
	1,500,000	2½	4½	5	..						
	1,750,000	3	5	5	..						
	2,000,000	3	5	6	..						

A Conduit capacities for various wires

Conduit	1 a	1 b	1 c	d	e
½	3	*10*	*18*	*5*	*3*
¾	5	*20*	*30*	*10*	*6*
1	10	*30*	*40*	*15*	*10*
1¼	18	*70*	*100*	*25*	*16*
1½	24	*90*	*130*	*35*	*25*
2	40	*150*	*200*	*50*	*35*
2½	74	...	...	..	..
3	90	...	...	..	..

1—Based on straight run without elbow.

a—No. 14 R. C. d. b. solid wires. **b**—No. 16 light insulation fixture wires. **c**—No. 18 light insulation fixture wires. **d**—No. 20 braided and twisted pair. Switchboard or desk instrument wire. Based on not more than two 90-degree elbows. **e**—No. 19 braided and twisted pair. Standard 3/32 insulation telephone wire. Based on not more than two 90-degree elbows.

189. Conduit should run as straight and direct as possible. There should never be more than the equivalent of four right-angle bends between drawing-in outlets.

190. Outlet boxes that are used for conduit wiring are of sheet steel, preferably coated with zinc. They not only hold the con-

duit ends firmly in position and form a pocket for enclosing wire joints but they constitute electrical connectors between the elements of the conduit system all of which must be in good electrical contact. Each conduit run in an installation must terminate in an accessible outlet box. Outlet plates are thinner than boxes and are used where the installation of outlet boxes is not feasible.

191. **Conduit outlet boxes** are made in many different forms (Figs. 133 and 134) and covers for them are also made in many different forms adaptable for special purposes. For ordinary work it is necessary to stock boxes of but two of these forms, the shallow box *II* and the combination box *X*. The shallow box which is designed primarily for outlets on terra cotta (Fig. 159) in fire-proof buildings can be used for ceiling outlets where it is convenient to enter the conduits into it from the back. Where the conduits should enter the sides or for combination fixture outlet work the combination box of Fig. 133, *X* can be used, when equipped with a suitable cover. Two of the knock-outs in the combination box are so formed that, when they are removed, either a round opening for conduit or an oblong opening for pipe is afforded. The shallow box which can be purchased with or without screw lugs for covers is cheaper than the combination box. The outlet plate *I* may be used where it is not feasible to use an outlet box.

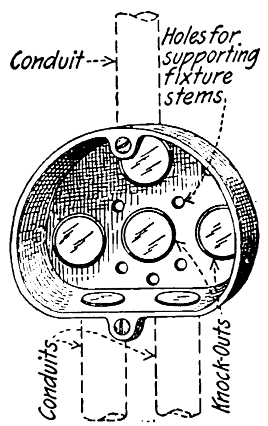


Fig. 134.—Bracket, outlet and junction box.

Outlet boxes are made of No. 10 to 12 gage sheet steel and Sherardized or galvanized ones are preferable to the japanned as with them the electrical conductivity of the conduit system is better preserved. Round boxes are made 3 in. and 4 in. in diameter. The 3-in. size is large enough for ordinary building wiring. Shallow boxes are about $\frac{1}{2}$ in. or $\frac{3}{4}$ in. deep. Standard round boxes for installation in brick are about $1\frac{1}{2}$ or $1\frac{5}{8}$ in. deep while those for lath and plaster are about $2\frac{1}{4}$ in. deep. This depth is necessary to insure that conduits entering the side knock-outs will clear the plaster. Square boxes are about 4 in. square and about $1\frac{5}{8}$ in. deep for brick and $2\frac{1}{4}$ in. deep for lath and plaster.

192. **All boxes should be installed** so that the outer edge of the box or the cover mounted on the box will come flush with the surface of the plaster. An outlet or junction box should never be concealed as concealment would defeat its purpose.

192A. **Switch outlet boxes** for one or two switches can be formed by equipping a square box with switch cover as at *XIV* and *XV*, Fig. 133. Where more than two switches are required in one group special outlet boxes for the group can be purchased.

193. **A special bracket, outlet and junction box** (Fig. 134) $3\frac{15}{16}$ in. in diameter and 2 in. deep is of great convenience where there are many bracket outlets to install in that two parallel conduits can be run into it as with a square box but at the same time its

diameter is such that a bracket canopy will cover it. A square box with a round-opening cover will accomplish the same end but the combination will cost more than the special box illustrated.

194. Every conduit outlet should be equipped with an outlet box or plate to satisfy code requirements. Although inspectors

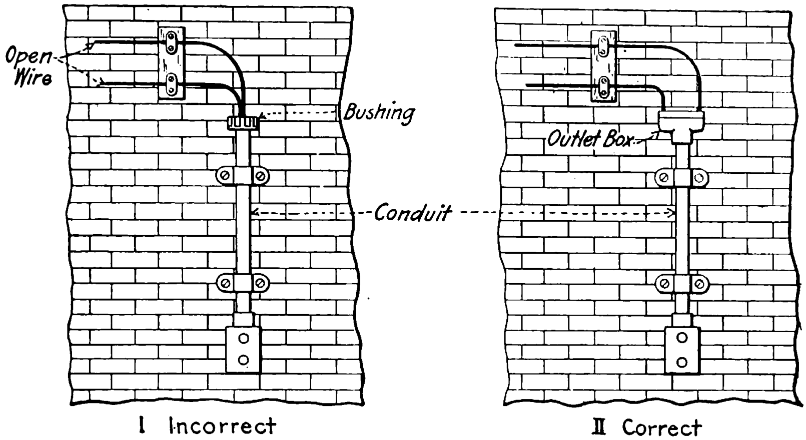


FIG. 135.—Outlet box on conduit.

sometimes accept the arrangement of Fig. 135 *I*, that shown in *II* is much better and should be used inasmuch as it provides the 2½-in. separation required for open wiring when the conductors are not enclosed in flexible tubing.

195. Conduit junction boxes which are in reality nothing more than pull boxes on a large scale are often very convenient at points

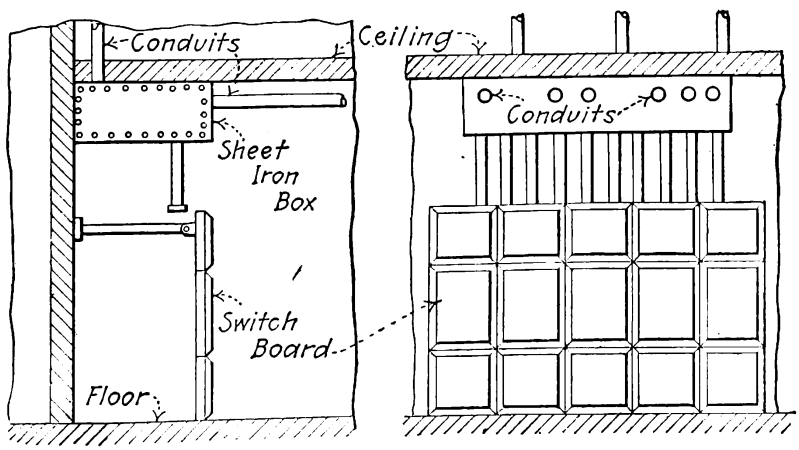


FIG. 136.—A sheet-iron conduit junction box.

where several conduit lines intersect, as for instance over a switchboard (Fig. 136) from which conduit lines radiate. The junction box is usually supported from the ceiling and is best made of sheet iron on an angle iron frame. The sides should be held on with

machine screws turning into tapped holes in the frame so that they can be readily removed. Round holes can be cut in the sheet-iron sides for the conduits or instead, and often preferably, slots can be provided. The conductors within the box can be carried from conduit outlet to conduit outlet in any direction desired, and the use of elbows and troublesome conduit crossings can, thereby, be avoided.

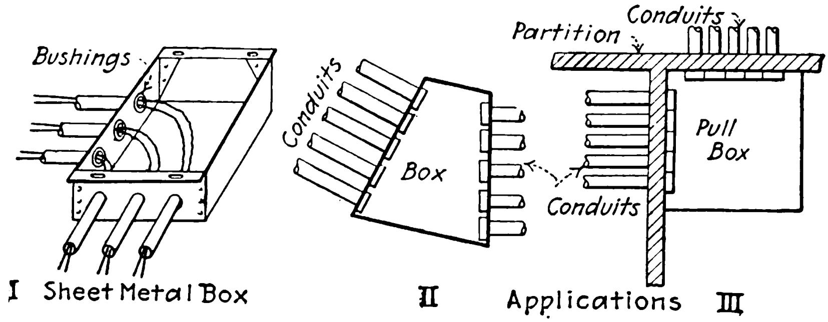


FIG. 137.—Conduit pull boxes.

196. Pull Boxes can often be Advantageously Substituted for Elbows (Fig. 137).—Large elbows are expensive. Where there are three or more right-angle turns in a run, a pull box should be inserted in any event. One pull box may be substituted for several elbows. Wire can be pulled in more readily where there are pull boxes hence, with them smaller conduit can often be used. Pull boxes can be made of sheet steel (Fig. 137, *I*) or of wood lined with sheet steel. Iron boxes should be made in accordance with the directions of a preceding paragraph (191). Boxes should be made and drilled in the shop where proper tools are available rather than on the job.

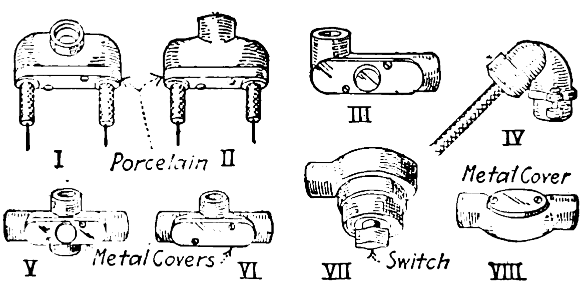


FIG. 138.—Some popular conduit fittings.

197. Conduit fittings are appliances used to adapt conduit to different situations and conditions. Fig. 138 shows some popular fittings, the applications of which are obvious. The code specifies that every conduit outlet must be equipped with an outlet box or plate. A fitting like that of *I* or *II* placed on a conduit end fulfils this requirement. Crosses, tees, and elbows *V*, *VI* and *III* can be obtained fitted with either metal covers or with outlet or other devices. The fitting of *IV* is used on the end of an out-of-

door piece of conduit into which wires enter. Its shape is such that wires must enter upwardly preventing the entrance of moisture. As it is almost impossible to pull wires through a fitting of this kind after it is in place it is therefore held to coupling on the end of the conduit with screws turning into a flange. The wires can be pulled into the conduit and the fitting slipped over them and attached to the flange without its being necessary to turn the fitting. The fittings of *VII* and *VIII* can be used either as pull boxes to support switches or for a number of other purposes. Everyone

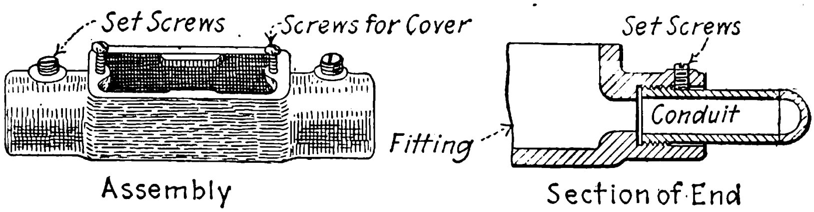


FIG. 139.—Pipe taplet.

interested in wiring should have the catalogues of the fitting manufacturers. These illustrate a great number of fitting combinations and applications.

198. "Pipe Taplet" fittings for conduit, Fig. 139 (H. T. Paiste, Philadelphia) have a set screw which assists the usual pipe threads holding the conduit. With Pipe Taplets it is necessary to cut only 4 or 5 full threads on the conduit. The steel set screws in the hubs of the fittings insure secure attachment and enable the wireman to accurately line up his conduit. Many different forms

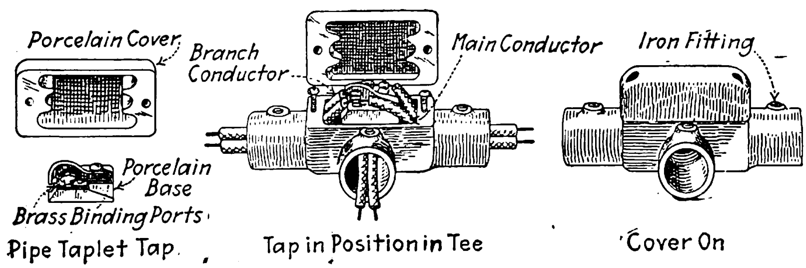


FIG. 140.—Pipe taplet tap.

of these fittings are made and many different kinds of outlet and appliance covers can be supplied for them. See the manufacturer's catalogue.

199. The Pipe Taplet Tap, Fig. 140 (H. T. Paiste, Philadelphia), is an exceedingly convenient appliance of porcelain with brass binding screws and strip. It fits in the Pipe Taplets described in the preceding paragraph. It is used for joining branch circuits to main circuits in conduit wiring. No soldering is necessary as the conductors are connected by clamping them under the binding posts. The porcelain cover encloses the completed splice. A

similar appliance is made for molding wiring applications. See the manufacturer's catalogue.

200. **"No-thread" fittings,** Fig. 141 (*Appleton Electric Co., Chicago*), can be used with unthreaded conduit. Tightening a bushing or a lock-nut, clamps the conduit within the fitting. Their application is objectionable in some instances because they do not look as well as fittings that expose no threads.

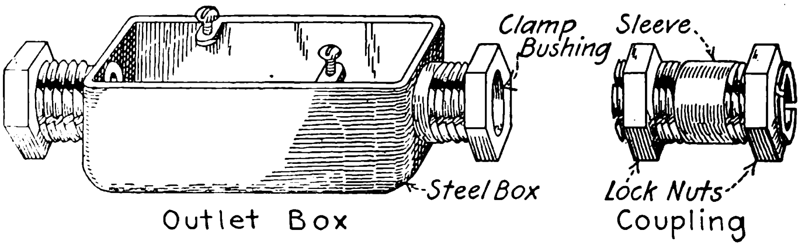


FIG. 141.—"No-thread" fitting.

201. **Properly bent conduit turns look better than elbows** and are therefore preferable for exposed work. See Fig. 142. If bends are formed to a chalk line, drawn as suggested in **202,** the conduits can be made to lie parallel at a turn in a multiple run as shown at Fig. 142, *II*. If standard elbows are used it is impossible to make them lie parallel at the turns. They will have an appearance similar to that shown at *I*.

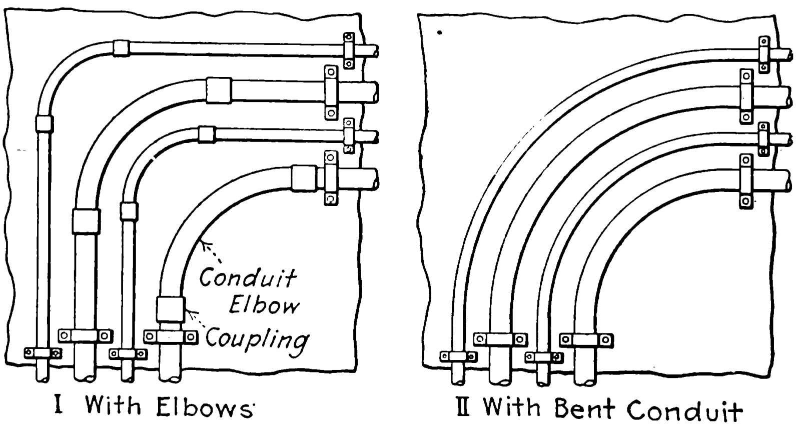


FIG. 142.—Right angle turns with elbows and with bent conduit.

202. **To Lay out a Right-angle Conduit Bend.**—Draw a chalk-line diagram of the contour of the bend on the floor as follows: See Fig. 143. Draw a base line *CO* of any length. Lay off *AO* 4 units long. (The units may be any dimensions whatever.) With a cord and a piece of chalk with *O* as a center and a radius of 3 units describe the arc *IJ*. With *A* as a center and a radius of 5 units describe the arc *EH*. The line *OD* drawn from *O* through *B*, the intersection of the two arcs, will be at right angles with *CO*.

CO and *OD* may now be prolonged for any desired distance. The arc *CD* is drawn with the cord and chalk with any required radius *R*. The conduit bend should lie parallel to this arc when the bend is laid on the floor for inspection as shown in Fig. 144. Table

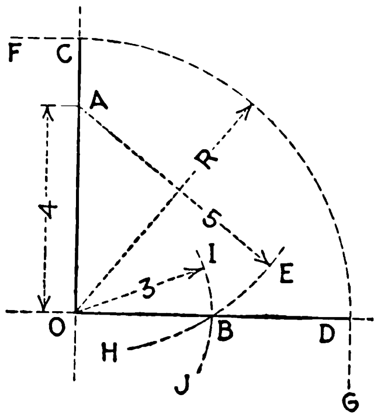


FIG. 143.—Laying out a right angle.

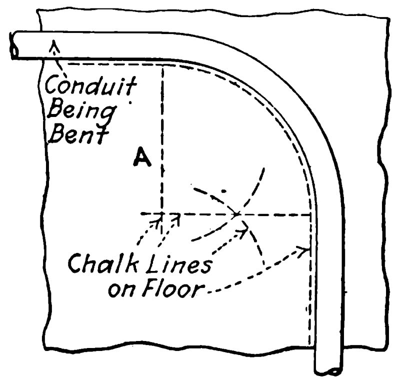


FIG. 144.—Forming a conduit to chalk lines.

173 shows the minimum radii that should be used for conduit bends.

203. Hand conduit benders are shown in Fig. 145. Many satisfactory commercial benders are obtainable but they usually

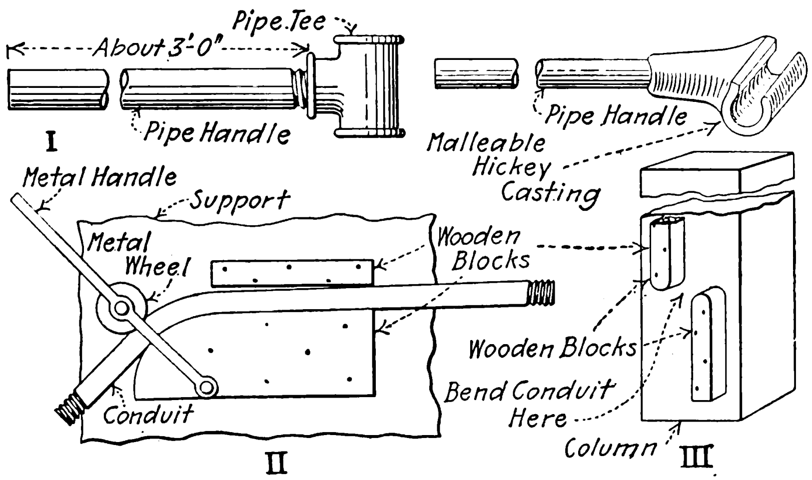


FIG. 145.—Some conduit-bending appliances.

have the disadvantage that the work must be carried to them to be bent. The "hickeys" shown at *I* can be used anywhere, hence are very popular. For ½- or ¾-in. conduit the "hickey" should be a 1-in. tee and pipe. A bender with a grooved metal wheel that any one can make is shown at *II*. The arrangement of *III* can be

used for large conduit. It consists of two heavy wooden blocks bolted to a column or other substantial vertical support.

204. To bend conduit by hand, butt the end in which the bend is not to be made against a wall or other vertical substantial object and mark off on the floor, with a line, the point where the bend should come. Slip the bender onto the pipe to a point within a

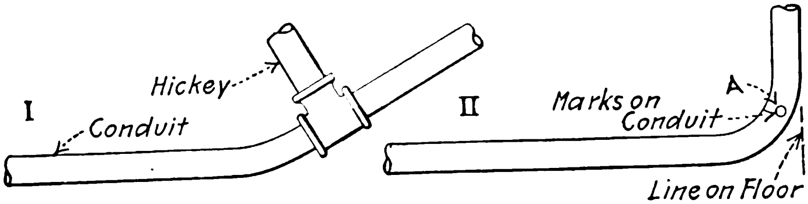


FIG. 146.—Bending conduit by hand.

couple of inches of the mark. Then bend the conduit about 20 degrees (Fig. 146, *I*). Move the bender back an inch or so and bend some more. Repeat until the bend assumes the proper form. Make all bends with as large a radius as possible. The minimum radius of inside of bend for any bend is $3\frac{1}{2}$ in. Where a line is drawn on the floor, conduit can be bent accurately to it (Fig. 146, *II*) but if a mark is placed on the conduit as at *A* it very difficult to make a proper bend.

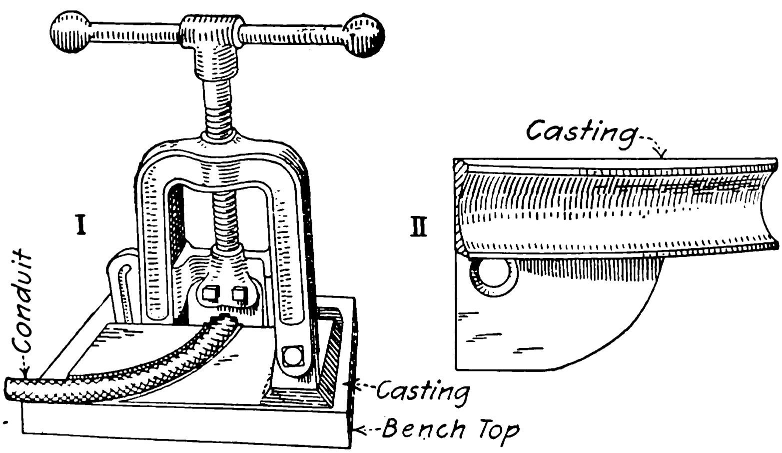


FIG. 147.—Combination vise and bender.

205. A combination conduit vise and bender for conduit of the smaller sizes is shown in Fig. 147. By bolting the casting shown at *II* to a commercial vise the arrangement shown at *I* results.

206. The best vise for large conduit is the so-called combination vise which is a combination of a pipe vise and a machinist's vise.

207. Cold Bending Large Conduit.—A rig for doing this is shown in Fig. 148. The bending rig can be set up in a door-way or between any strong vertical supports. It is usually cheaper to bend large elbows than to buy them. Always carefully lay out a

chalk line (see **202**) on the floor to bend to before starting. In forming a bend, start at one end of the curve that is to be, bend a little with the jack screw and then take the conduit out and to the chalk line and compare it therewith. Proceed thus until the bend required is formed. A hydraulic rather than a screw jack may be necessary for conduits larger than 2 in. diameter.

The wooden form by means of which the jack screw's pressure is applied to the conduit is detailed in Fig. 149. It should be of a

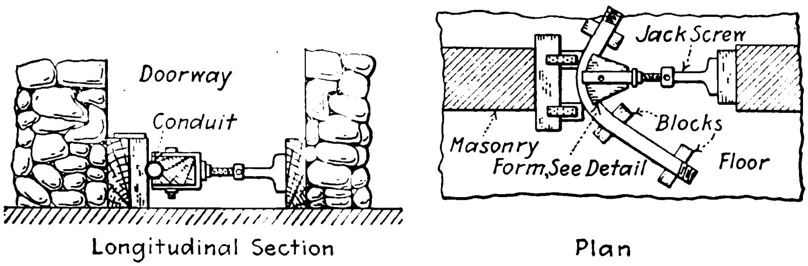


FIG. 148.—Cold bending conduit with a jack-screw.

hard close-grained wood such as maple. The diameter of the groove should be a trifle larger than that of the conduit. There should be a block for each size conduit, but sometimes a conduit can be successfully bent with a block for a larger size. If the groove does not fit, the pipe may crush. The iron strap reinforces the groove. The bolt should fit the hole for it in the block tightly or the block may crush. The radius *R* (Fig. 143) should be not less than that of standard elbows; see Table **173**. The minimum, inside radius, is $3\frac{1}{2}$ in.

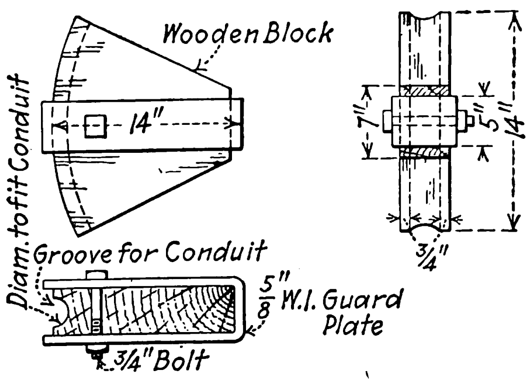


FIG. 149.—Wooden form for bending conduit.

208. Threading Conduit.—The same dies that are used by steam and gas fitters for threading pipe are used for threading conduit. It is usual practice when a lot of conduit is received to rethread all of the ends which may have become filled with paint or dirt or distorted by blows. Rethreading will save more than its cost in that it insures rapid erection. Always rebream conduit after cutting a thread on it.

209. **Pipe-threading machines for threading conduit,** preferably those operated by motors, should be used on big jobs and will soon pay for themselves in the time that they save.

210. **Running thread joints** (Fig. 150) are sometimes used when it is necessary to connect the ends of two lengths of conduit neither of which can be turned. Running threads are often used in making

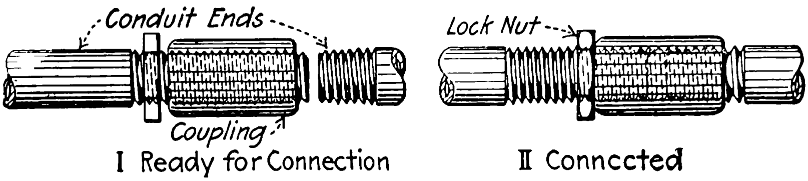


FIG. 150.—A running thread.

repairs to or alterations in existing conduit installations. The function of a running thread joint is similar to that of the pipe union used in steam and gas fitting.

To make a running thread joint, the thread on one length of conduit (Fig. 150) is cut sufficiently long that the coupling can be run entirely on it while the adjacent length is being fitted into

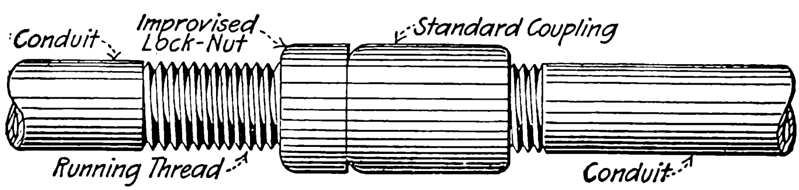


FIG. 151.—Showing lock-nut sawed from coupling.

position. The adjacent length has the usual "short thread." After both lengths are in position the coupling is turned until it wedges up tightly on the short thread. About half of the coupling should, in the completed joint, rest on each length (Fig. 150, *II*).

A lock-nut should be used, as shown, on the long thread length to hold the coupling firmly in the conduit as it is apt, otherwise,

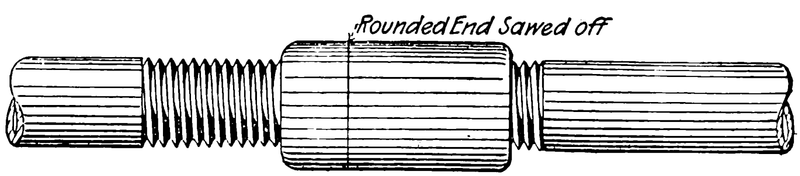


FIG. 152.—Coupling end sawed off to make flush joint.

to fit loosely because of the long thread. An excellent lock-nut can be made by sawing off, with a hack-saw, about one-third of a coupling and using this third, as shown in Fig. 151. The standard, hexagonal, conduit lock-nut often gives trouble because it has only a few threads and they may be "loose." Where a very neat job is required, saw off the rounded end of the standard coupling so

that the sawed end of the improvised coupling lock-nut will have a square surface on which to abut. See Fig. 152 for an illustration.

210A. The Erickson coupling (Fig. 152, *A*), was devised for the same applications as those for which the running thread is used. The illustration shows the construction of the device.

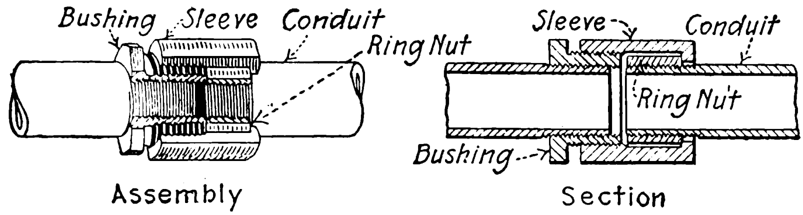


FIG. 152A.—The Erickson coupling.

211. Wrenches for Turning Conduit.—The form of wrench shown in Fig. 153, *I*, appears to be the most popular for turning conduit. Chain wrenches (*II*) are not as yet much used for conduit work but in instances where they have been tried they have proven very satisfactory. Their advantages lie in the facts that they can be used with one hand after the chain is around the conduit and

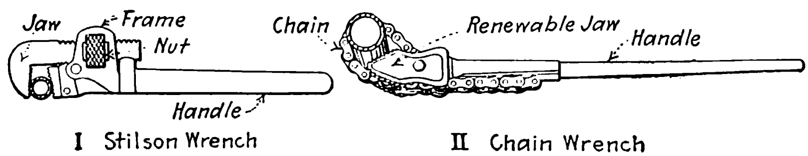


FIG. 153.—Wrenches for conduit.

that they can be used in confined places and close to walls where a Stilson wrench could not be utilized.

212. Conduit ends should always be reamed. A reamer like that of Fig. 154 that can be turned by a bit brace is a good tool for small and medium size conduit. For conduit of the larger sizes, reamers can be obtained which have long handles attached, giving

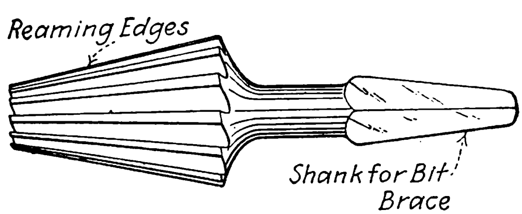


FIG. 154.—A bit-brace reamer.

the needed leverage. When conduit is received, and after it is cut, the ends are frequently turned in (Fig. 155, *I*) and when screwed together in a coupling form a knife-like edge which will abraid insulation. When the ends are properly reamed they appear as shown in Fig. 155, *II*, but if they are screwed together too tightly they may turn up as at *I*, defeating the thing that reaming should

accomplish. Where no other tool is available, conduit can be reamed by hand with a half-round file.

213. The best tool for cutting conduit is a hack saw. Pipe

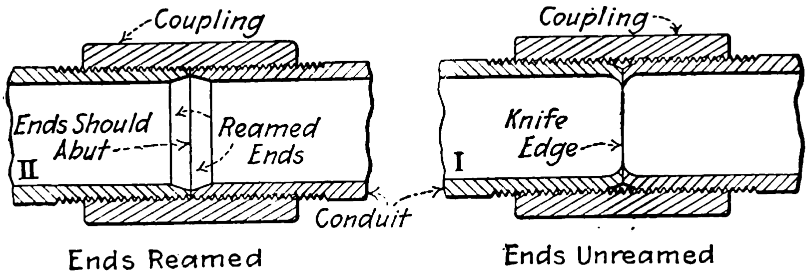


FIG. 155.—Reamed and unreamed conduit ends.

cutters are frequently used but leave a large burr on the inside of the conduit which takes time to ream out. While cutting, the conduit should be held in a vice. On jobs where there is a great deal of conduit to cut, the installation of a motor-driven cold-cut-off saw, such as is used for cutting structural steel and rails, will prove economical. A rapidly rotating steel disc without teeth cuts the pipe. Water must be sprayed on the disc to keep it cool.

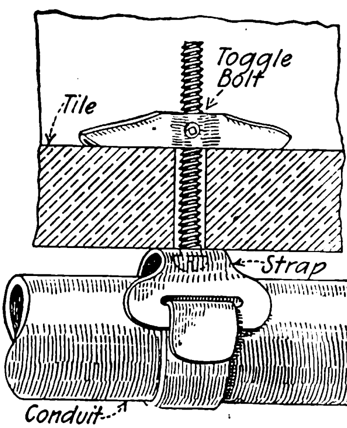


FIG. 156.—Conduit toggle bolt.

214. In installing exposed conduit runs where there are several conduits in the run it is usually better to carry the erection of all of them along together rather than to complete one line before starting the others. If all are carried along together it is easier to maintain all of the ducts parallel, particularly at turns, and the chances are that the job will thereby look better.

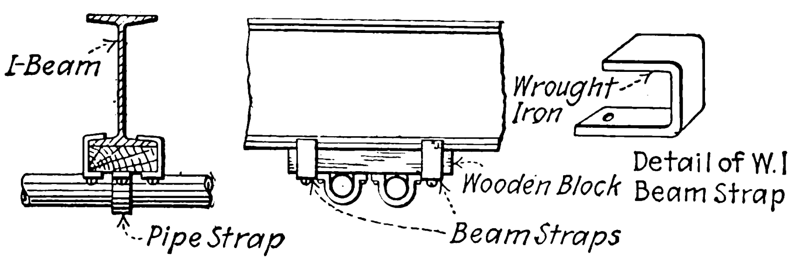


FIG. 157.—Application of beam straps.

215. A hanger for supporting conduit on hollow tile (Fig. 156) is made by the Yonkers Specialty Co., Yonkers, New York. With it only one hole is necessary through the tile which is considerably

weakened by the two holes and plugs close together that are necessary for a pipe strap. The flexible metal strap is bent around the pipe and through the slot after the conduit is in position.

216. Conduit can be supported on surfaces with pipe straps (Table 183). On wooden surfaces wood screws secure the straps in position. On masonry surfaces wood screws turning into wooden plugs driven in holes in the surface or turning into lead expansion anchors can be used. Wooden plugs are apt to be unsatisfactory because no matter how well seasoned a plug appears to be it will usually dry out some and loosen in the hole. Where

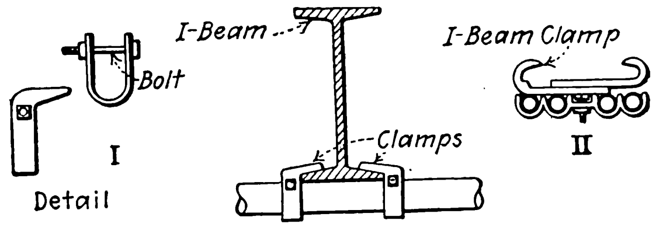


FIG. 158.—Commercial conduit clamps.

conduit is carried on the flanges of I-beams one of the many commercial clamps can be used or the one referred to in **219** can be applied. Conduit can also be supported on an I-beam by first clamping a wooden block to the beam and then securing the conduit to the block with pipe straps. (See Fig. 157.)

217. Some commercial I-beam conduit hangers are shown in Fig. 158. The one at *I* is an I-beam clamp formed from wrought-iron strap. The hanger or clamp—the part that grips the beam—of that at *II* can be purchased of either stamped steel or malleable

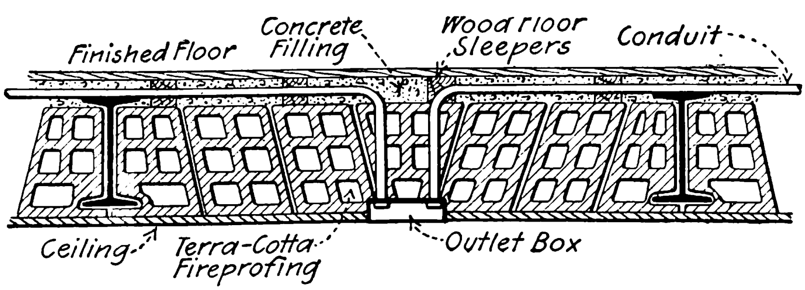


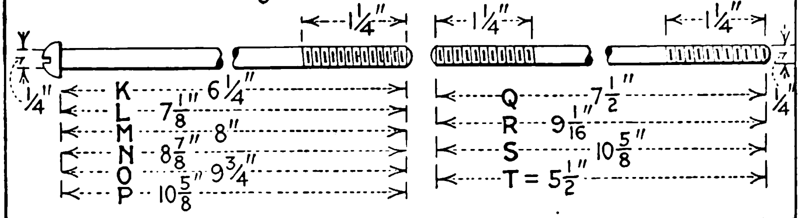
FIG. 159.—A fixture outlet in a terra-cotta ceiling.

iron. The support—the yoke in which the conduits rest—is of malleable iron and can be purchased to accommodate one or several conduits of different sizes.

218. Conduit in fire-proof buildings is usually carried over and is supported by the floor beams (Fig. 159) when carried within the floors. Where necessary the terra-cotta fire-proofing is channeled to receive it. In vertical runs in walls or partitions the fire-proofing is either channeled for or built around the conduit which is held in place prior to plastering with cut nails or pipe hooks.

219. The I-beam conduit clamps of Table 220 will be found of great convenience in steel mill and fire-proof building work. Their principal advantage is that they draw the conduit up closely against the I-beam and grip it very firmly. In a multiple-conduit run each conduit can be secured to a given beam with its own pair of clamps. Where the clamps are used on conduits in a group that lie close together the stove bolts should be used in

In case studs are used instead of stove bolts:– Use "Q" studs for all combinations in left hand section of table, use "R" studs for all combinations in center section, and "S" studs for all combinations in right hand section.



CONDUIT	SIZE OF I BEAMS								
	4"	6"	7"	8"	9"	10"	12"	15"	18"
½"	T 5½"	K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
¾"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1¼"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1½"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
2"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
2½"		K 6¼"	K 6¼"	K 6¼	L 7⅛"	L 7⅛"	M 8"	N 8⅞"	P 10⅝"
3"		K 6¼"	K 6¼	K 6¼"	L 7⅛"	L 7⅛"	M 8"	N 8⅞"	P 10⅝"
3½"		K 6¼"	L 7⅛"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	O 9¾"	P 10⅝"
4		K 6¼"	L 7⅛"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	O 9¾"	P 10⅝"
		←	Q	→		← R	→	← S	→

FIG. 160.—Dimensions of store bolts and studs for the conduit clamps of Fig. 161.

preference to the studs so that they can be drawn up with a screw driver. For a single isolated conduit either studs or stove bolts can be used.

Fig. 160 shows the size of the stove bolts or of the studs, that should be used with a given I-beam and a conduit of a given size. Stove bolts of the sizes indicated are regularly manufactured, but are not always readily obtained. The studs can be easily made by threading the ends of ¼-in. wrought iron rod. In cramped locations the nuts on the studs can be tightened with pliers.

220. Dimensions of I-beam Conduit Clamps.—Clamps to be made of cast or malleable iron. See Fig. 160 showing dimensions of stove bolts and studs for clamps.

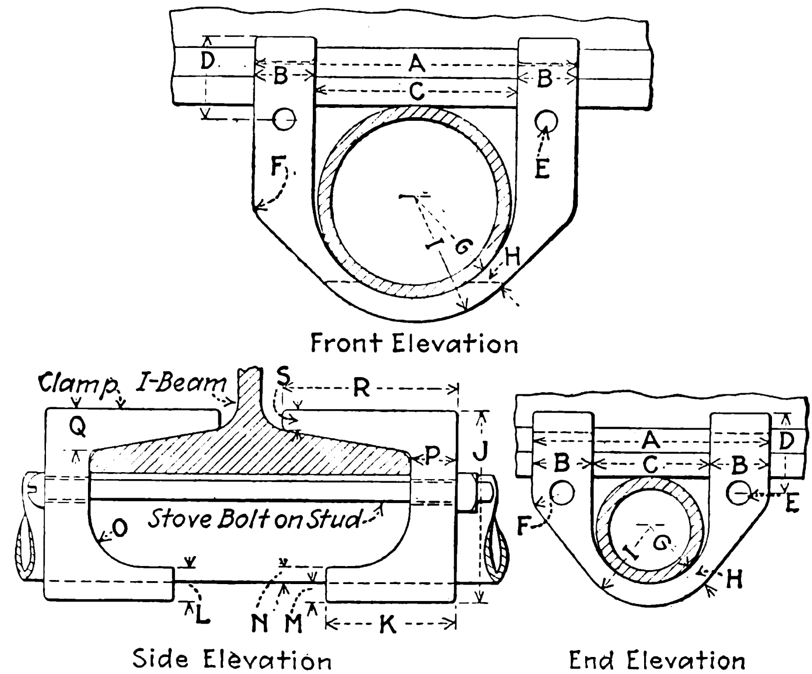


FIG. 161.—I-beam conduit clamp.

Size conduit, inches	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
[1] ½ 4″ beam	2 5/16	11/16	15/16	3/4	5/16	11/32	15/32	1/4	23/32	1 11/16	1 1/2	3/8	1/4	1/8	1/2	1/2	11/32	1 1/2	3/16
½	2 5/16	11/16	15/16	1 1/8	5/16	11/32	15/32	1/4	23/32	2	1 1/2	3/8	1/4	1/8	1/2	1/2	15/32	2 1/8	3/16
¾	2 1/2	11/16	1 1/8	1 1/8	5/16	11/32	9/16	1/4	13/16	2 1/4	1 1/2	3/8	1/4	1/8	1/2	9/16	15/32	2 1/8	3/16
1	3	3/4	1 1/2	1 7/32	5/16	3/8	3/4	1/4	1	2 5/8	1 5/8	7/16	1/4	3/16	11/16	9/16	33/64	2 3/16	1/4
1¼	3 1/4	3/4	1 3/4	1 3/16	5/16	3/8	7/8	1/4	1 1/8	2 29/32	1 5/8	7/16	1/4	3/16	11/16	9/16	33/64	2 3/16	1/4
1½	3 1/2	3/4	2	1 3/16	5/16	3/8	1	5/16	1 5/16	3 3/16	1 7/8	1/2	5/16	3/16	11/16	9/16	33/64	2 3/16	1/4
2	4	3/4	2 1/2	1 1/4	5/16	3/8	1 1/4	5/16	1 9/16	3 3/4	1 7/8	1/2	5/16	3/16	1 1/8	5/8	37/64	2 1/4	5/16
2½	4 3/4	7/8	3	1 15/32	5/16	7/16	1 1/2	5/16	1 13/16	4 1/2	2	9/16	15/16	1/4	1 1/4	11/16	41/64	2 5/16	3/8
3	5 3/4	1	3 3/4	1 5/16	5/16	1	1 7/8	3/8	2 1/4	5 1/8	2 1/8	9/16	3/8	3/16	1 1/4	11/16	41/64	2 3/8	3/8
3½	6 3/4	1 1/4	4 1/4	1 3/8	5/16	1 1/4	2 1/8	1/2	2 5/8	5 11/16	2 1/4	11/16	1/2	3/16	1 1/4	13/16	11/16	2 15/32	7/16
4	7 1/2	1 3/8	4 3/4	1 7/16	5/16	1 3/8	2 3/8	1/2	2 7/8	6 1/4	2 1/4	3/4	1/2	1/4	1 1/4	13/16	29/32	2 7/16	1/2

[1] This clamp is designed for 4-in. I-beams only.

221. Conduit in concrete buildings—much of it at any rate—should be installed while the building is being erected. The outlets and the conduit between outlets should be attached to the forms and the concrete can be poured around them (Fig. 162). Where several conduits are to pass through a wall, partition or floor, a plugged sheet-iron tube (Fig. 163, *I*) should be set in the forms

to provide a hole for them in the concrete. Where a single conduit is to pass through, a nipple (Fig. 163, *II*) can be set in the forms. A running thread should be provided on the nipple so that the adjacent conduit lengths can be connected to it.

222. **Another method of supporting conduit in concrete buildings** is described in 83 and is illustrated in Fig. 60.

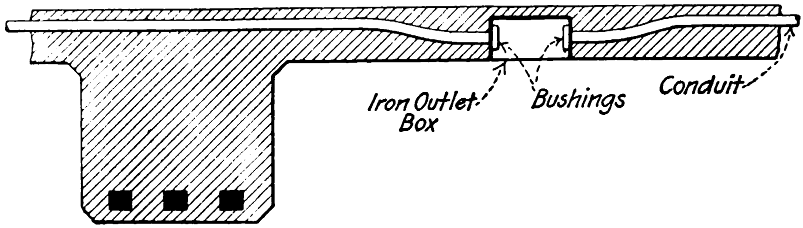


FIG. 162—Conduit and outlet box in concrete.

223. **Conductors in vertical conduits must be supported** within the conduit system as indicated in the following table.

No. 14 to 0 inclusive every 100 ft.
00 to but not including 0000 every 80 ft.
0000 to but not including 350,000 C. M. every 60 ft.
350,000 C. M. to but not including 500,000 C. M. every 50 ft.
500,000 C. M. to but not including 750,000 C. M. every 40 ft.
750,000 C. M. and over every 35 ft.

The following methods of supporting cables are recommended by the Underwriters:

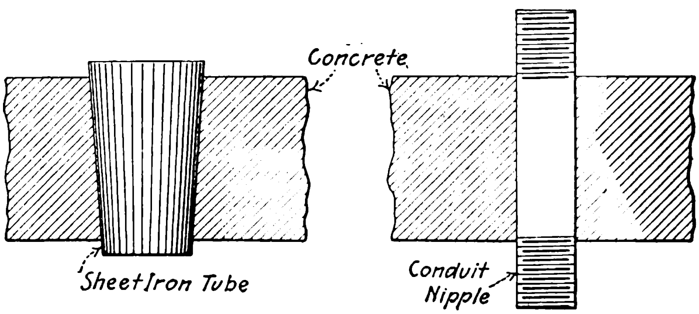


FIG. 163.—Methods of providing passages through concrete.

1. Approved clamping devices constructed of or employing insulated wedges inserted in the ends of the conduits.

2. Junction boxes may be inserted in the conduit system at the required intervals, in which insulating supports of *approved* type must be installed and secured in a satisfactory manner so as to withstand the weight of the conductors attached thereto, the boxes to be provided with proper covers.

3. Cables may be supported (Fig. 164) in *approved* junction boxes on two or more insulating supports so placed that the conductors will be deflected at an angle of not less than 90 degrees, and carried a distance of not less than twice the diameter of the cable from its vertical position. Cables so suspended may be additionally secured to these insulators by tie wires.

Other methods, if used, must be approved by the Inspection Departments having jurisdiction.

224. Fishing wire (*Popular Electricity*, Apr. 7, 1912) is tempered steel wire of rectangular cross-section. It is a grade of wire that is used sometimes for corset steels and can be obtained at corset factories and at electrical supply houses. A fishing wire is termed a "snake" by some wiremen. See Table 227. So that a fishing wire will slide readily past small obstructions, hooks should be bent in its ends as shown in Fig. 165. Before bending, the ends should be annealed by heating them to a red heat and allowing them to cool slowly. A small brass knob riveted to the end of a fishing wire (Fig. 166), is better than a hook as regards the ease with which the wire can be pushed through conduit. Where fishing is difficult, it is sometimes necessary to push two "snakes" with hook ends into the wire way, one from each of the outlets, as shown in Fig. 165. The wires must be worked back and forth and twisted around until the two hooked ends engage. Then one wire can be pulled into the duct with the other. The Swan fishing wire for conduit, shown in Fig. 167, has a patented coupling on one end and a patented "drawing-in-eye" on the other, which can be made to engage within conduit, as shown in the illustration.

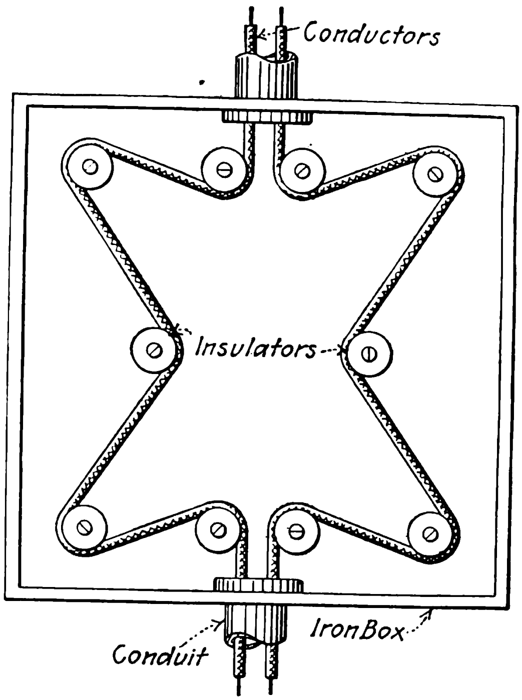


FIG. 164.—Supporting conductors in a vertical conductor run.

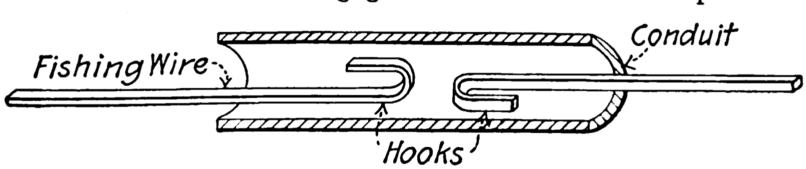


FIG. 165.—Hooks bent in fishing wire ends.

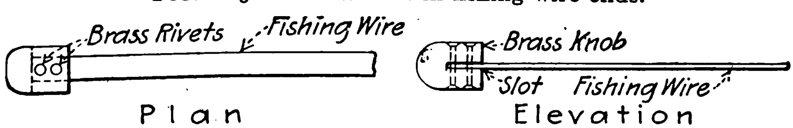


FIG. 166.—Knob on end of fishing wire.

When fishing from two ends, as in Fig. 165, it is often advisable to tie a loop, possibly a foot long, of cord, in the hook of one wire and bend down the hook (Fig. 168). The other wire has an open hook which can be made to engage in the cord loop quite readily.

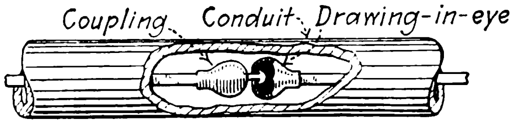


FIG. 167.—"Swan" coupling and drawing-in eye.

It has been found that a fish wire will go through conduit more readily if prepared as in Fig. 169, by loosely winding the end with small wire or cord, so that the wire or cord cannot pull off. Oiling a fish wire or attaching an oil-soaked piece of waste to its end often helps in fishing conduit.

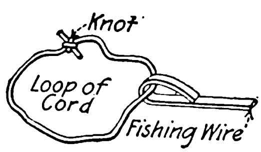


FIG. 168.—Cord loop on end of fishing wire.

225. Chain is used for vertical fishing. A small chain can be made to drop down a vertical wire way with little difficulty. Within a partition, the noise made by the lower end of a chain that is jiggled up and down will disclose its location almost exactly.

226. Galvanized steel wire can be used for fishing. Any size from No. 14 up to, possibly, No. 6, as occasion demands, may be utilized, but in nearly every case the flat steel ribbon wire will be found preferable.

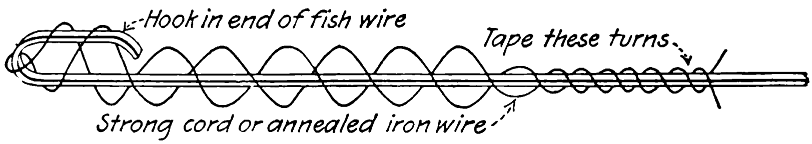


FIG. 169.—Fish wire end prepared with cord.

227. Dimensions of Steel Fish Wire

The $\frac{1}{4}$-in. wide wire is the size most frequently used. The wire is usually put up in coils of 50, 75, 100, 150 and 200 ft.

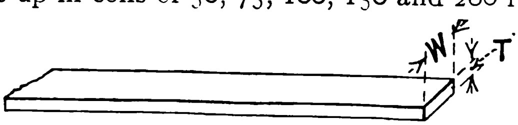


FIG. 170.—Steel fishing wire.

W Width, inches	T Thickness, inches	Weight, per 100 ft.	Approximate price, cents	
			Per pound	Per foot
$\frac{1}{8}$	0.015	11 oz.	90.0	0.62
$\frac{1}{8}$	0.030	1 lb. 4 oz.	60.0	0.75
$\frac{3}{16}$	0.030	1 lb. 14 oz.	60.0	1.13
$\frac{1}{4}$	0.030	2 lb. 8 oz.	60.0	1.50
$\frac{5}{16}$	0.035	3 lb. 8 oz.	55.0	1.93
$\frac{3}{8}$	0.035	3 lb. 12 oz.	55.0	2.06

228. **Where conduit cannot be fished with a steel fishing wire** because of some obstruction, it is often possible to blow through, with the mouth or with a plumber's force pump, a ball of cork of a diameter somewhat less than that of the conduit. Attached to the cork ball is a small strong cord (fish line) which can be used for pulling in a length of small wire which, in turn, can be used for drawing in the conductors. Put the ball in the conduit and feed

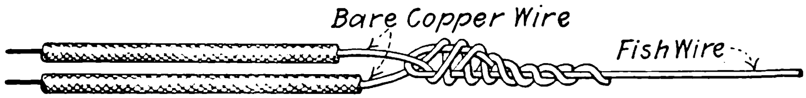


FIG. 171.—Attachment of conductor to fishing line.

in some string, then blow. With a plumber's pump, a tee is necessary on the end of the conduit; one opening is used for feeding in the string and the other for the pump blast. Close the cord opening when blowing.

229. **In drawing wire into conduit** (*Practical Engineer*, Apr. 17, 1912), it is a mistake to use so much force that the wire cannot be withdrawn. Conduits should be big enough so that excessive force

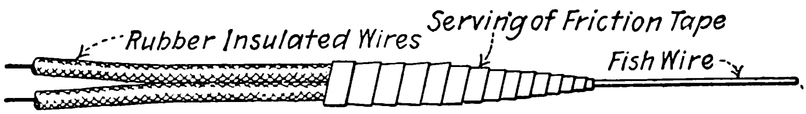


FIG. 172.—Attachment taped over.

is not necessary. Duplex No. 14 conductors can often be pushed through "easy" runs. Small conductors (No. 14 and No. 12) can be pulled in with the fish wire. Fig. 171 shows how they can be attached to the fish wire and Fig. 172 how the attachment should be served with tape to render pulling easy. It spoils any fishing wire to draw in with it conductors that pull hard.

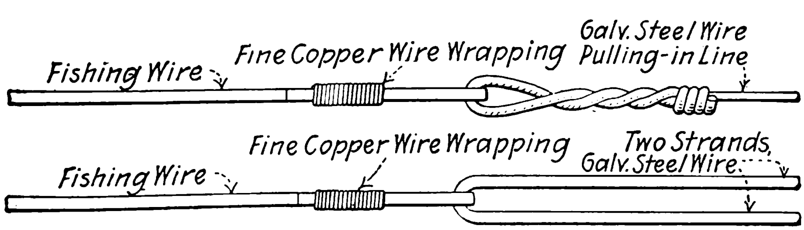


FIG. 173.—Attachment of pulling-in line to fish wire.

For conductors larger than No. 12 and No. 14, unless the "pulls" are "very easy," a pulling-in-line which is drawn into the conduit with the fish wire should be used for hauling in the conductors. No. 10 or No. 12 B.W.G. galvanized steel wire makes a good pulling-in-line and is probably better for heavy work than rope. Two strands can be used if necessary. Braided cord is better than twisted rope for a pulling-in-line, because when tension is applied,

the rope tends to untwist. Sash cord is satisfactory for light work. Galvanized steel pulling-in-wire can be attached to fish wire as in Fig. 173.

Three or four links from a chain of no greater diameter than the line should be made up in the end of a rope or cord pulling-in-line. Wires to be drawn in or a fish line can be attached to the links (Fig. 174). One stranded conductor can be attached to a pulling-in-line as in Fig. 175. The attachment should be taped over to make it smooth. If two conductors are to be pulled in, one of them is "made up" into a loop in the end of the pulling-in-line, as shown in Fig. 175. The insulation is trimmed from this conductor for

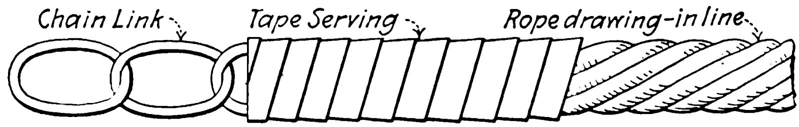


FIG. 174.—Chain links in end of pulling-in line.

6 in. or more and the bared end of the other conductor is made up about the first one, forming a long tapering connection. If a hard pull is expected, it is advisable to solder the connection. The whole should be served with tape as in Fig. 172. If three wires are to be drawn in instead of two, the attachment is the same with the addition that the bared end of the third conductor is made up around the other two. The diameter at any section of the attachment must not exceed the over-all diameter of the wires and the attachment should be in the form of a conical wedge. It is sometimes necessary to cut off, possibly, half of the strands of the bared ends and make up only the strands that remain to insure that the attachment will be of sufficiently small diameter.

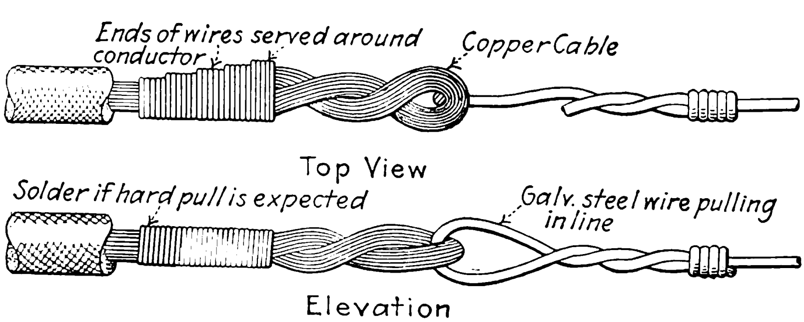


FIG. 175.—Attachment of stranded conductor to pulling-in line.

230. Force for pulling in conduit is, in the case of easy pulls, supplied by men. Tackle blocks are permissible for heavy pulls. Cranes can often be used very effectively where they are available. Snatch blocks can be used to guide the pulling-in-line to some point where it can be either pulled with the crane hook or by the crane in traveling along its runway. A lever can be used for hard pulls by either repeatedly fastening the pulling-in-line to the lever

or by gripping it with a pair of pliers and then prying against the pliers with the lever. Only a short pull is possible with each setting and a succession of settings and prys is necessary to draw the conductor in.

231. **In feeding conductors into conduit,** care must be taken that they go in symmetrically and without lapping or twisting. If one conductor crosses another it may make a "hump" that will wedge in the conduit. Soapstone blown into conduit renders pulling easier. One convenient way to get the powdered soapstone into the ducts is to place it in an elbow, place the elbow to the conduit and then blow on the elbow. Powdered soapstone should be rubbed on the conductors as they are drawn into conduits where the pulls are hard.

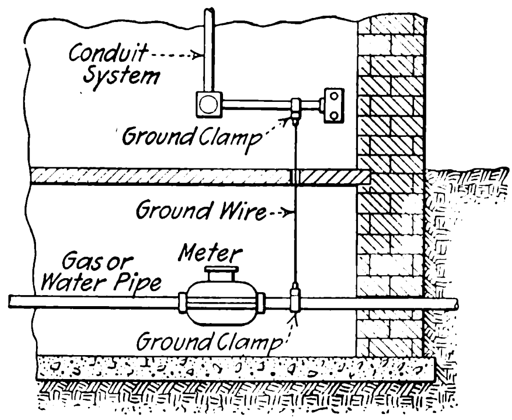


FIG. 176.—Method of installing ground on conduit system.

232. **Conduit systems must be grounded** by attaching a ground clamp (Fig. 176) to a conduit of the system and connecting it by a ground wire with a similar clamp attached to a water or gas pipe outside of the meter. The wire must be soldered in the clamps. All parts of the conduit system must be in good electrical contact. It may be necessary to scrape or file enamel from fittings or from conduit threads to effect this. If a conduit system is not grounded and one side of the circuit comes in contact with the conduit, an electrical path may be completed if the other side of the circuit happens to be grounded. (The neutral wire of a three-wire system is usually grounded.) The electrical path thus completed might be through damp wood or a contact with a gas pipe. A fire might result. With the conduit well grounded such a short-circuit would blow a fuse and thereby reveal itself. With combination fixtures the gas pipe should be in firm electrical contact with the conduit system at each outlet box.

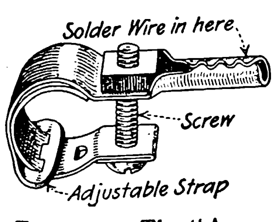


FIG. 177.—The "American" adjustable ground clamp.

233. **Wire for grounding conduit** must be of copper, at least No. 10 B. & S. gage, where the largest wire contained in conduit is not greater than No. 0 B. & S. gage. It need not be greater than No. 4 B. & S. gage where the largest wire contained in conduit is greater than No. 0 B. & S. gage. The wire must be protected from mechanical injury.

234. **An excellent ground clamp** (the American made by the Chelten Electric Company, Philadelphia) is shown in Fig. 177. It is adjustable and is made in four sizes. No. 1 fits $\frac{3}{8}$-in., $\frac{1}{2}$-in.,

$\frac{3}{4}$-in., and 1-in. conduit or pipe. No. 2 fits 1 $\frac{1}{4}$-in., 1 $\frac{1}{2}$-in., and 2-in. and No. 3 fits 2 $\frac{1}{2}$-in. and 3-in.

235. **Flexible metallic conduit** (*Standard Handbook*) may be used for all kinds of wiring; being in some cases preferable to rigid conduit. Its installation is much easier and quicker than the installation of rigid conduit, the latter coming in short pipe lengths, whereas the former may be had in lengths of 50 to 200 ft. depending on the size of the conduit. Practically the same *Nat. Elec. Code* rules apply to the flexible as to the rigid conduit. Rubber-covered wire must be used; outlet or switch boxes must be installed at all outlets or switches; the conduit must be continuous from outlet to outlet, must be securely fastened to the boxes and provided with proper bushings and must be permanently and effectually grounded with a copper wire. (See Par. 233.)

Its flexibility together with the continuous length procurable make its use practicable when rigid conduit would be out of the question. For this reason it may be employed to advantage in finished houses and in frame buildings in place of the other forms of wiring so largely employed in these structures. The conduit is easily fished and requires no elbow fittings. These may be made with the conduit itself; but care should be exercised in properly fastening the conduit at elbows. (Fig. 180.) Fittings are on the market whereby changes from other forms of wiring may be easily made to flexible conduit wiring. Iron plates should be used to protect the conduit from nails, where it passes through slots in floor beams or studding.

235A. Greenfield Flexible Steel Conduit

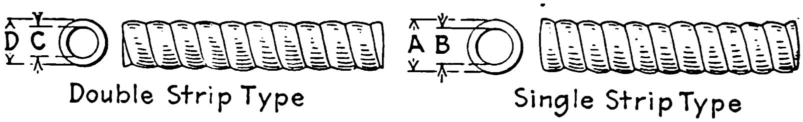


FIG. 178.—"Greenfield flexible steel conduit.

SINGLE-STRIP TYPE

B Nominal inside diameter in inches	A Approximate outside diameter in inches		Weight per 100 ft. in pounds	Approximate feet in coil	List price per 100 ft.	Largest wires accommodated		
						1 wire	2 wires	3 wires
$\frac{5}{16}$	0.523	$\frac{17}{32}$	24	250	$5.00	....	....	.....
$\frac{3}{8}$	0.605	$\frac{39}{64}$	30	250	7.50	....	....	.....
$\frac{1}{2}$	0.875	$\frac{7}{8}$	55	100	10.00	8	12	.....
$\frac{3}{4}$	1.079	1 $\frac{3}{32}$	75	50	13.00	2	10	12
1	1.312	1 $\frac{5}{16}$	122	50	21.00	00	0	8
1 $\frac{1}{4}$	1.59	1 $\frac{19}{32}$	170	50	31.00	200,000	3	5
1 $\frac{1}{2}$	1.875	1 $\frac{7}{8}$	188	25–50	42.00	400,000	1	3
2	2.375	2 $\frac{3}{8}$	263	25–50	57.00	800,000	200,000	00
2 $\frac{1}{2}$	3	3	306	25	70.00	....	....	.....

DOUBLE-STRIP TYPE

C	D							
$\frac{5}{16}$	0.485	$\frac{1}{2}$	20	250	$5.00	......	......	.....
$\frac{3}{8}$	0.61	$\frac{5}{8}$	34	250	7.50	......	......	.....
$\frac{1}{2}$	0.92	$\frac{59}{64}$	68	100	10.00	8	12	.....
$\frac{3}{4}$	1.18	$1\frac{3}{16}$	95	50	13.00	2	10	12
1	1.49	$1\frac{1}{2}$	144	50	21.00	00	0	8
$1\frac{1}{4}$	1.75	$1\frac{3}{4}$	182	50	31.00	200,000	3	5
$1\frac{1}{2}$	2.06	$1\frac{1}{16}$	217	25–50	42.00	400,000	1	3
2	2.56	$1\frac{9}{16}$	265	25–50	57.00	800,000	200,000	00

236. Installation of Flexible Steel Conduit and Flexible Steel Armored Conductors.—Where exposed they may be clamped to the surface wired over either with pipe hooks or with pipe straps. Where concealed they can be fished into place just as any other concealed conductors are fished in.

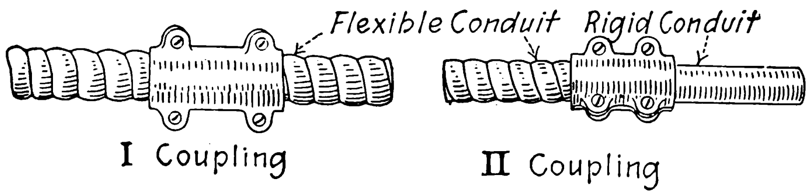


FIG. 179.—Couplings for flexible steel conduit.

237. Flexible steel conduit is joined with clamps as illustrated in Fig. 179. Short lengths can be coupled to longer pieces with the clamp of *I* and waste thereby prevented. The clamp at *II* is used for coupling rigid to flexible conduit.

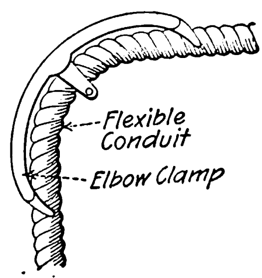


FIG. 180.—Elbow clamp.

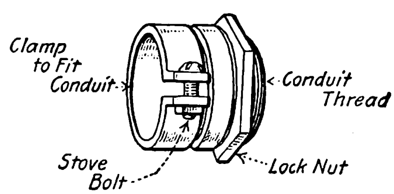


FIG. 181.—Connector for attaching flexible steel conduit to an outlet box.

238. Where elbows are formed in flexible conduit some provision must be made to prevent the conduit from straightening out thereby preventing the withdrawal of the conductors. Pipe straps can be used in some cases and in others an elbow clamp (Fig. 180) can be applied.

239. Flexible steel armored conductors and flexible steel conduit can be connected into steel boxes with the connector illustrated in Fig. 181. The fitting shown is of Sprague manu-

facture and is formed from sheet steel and galvanized. It is clamped to the armor with a bolt which insures good electrical connection between armor and steel box. Fig. 182 shows flexible steel conduit connected into an outlet box.

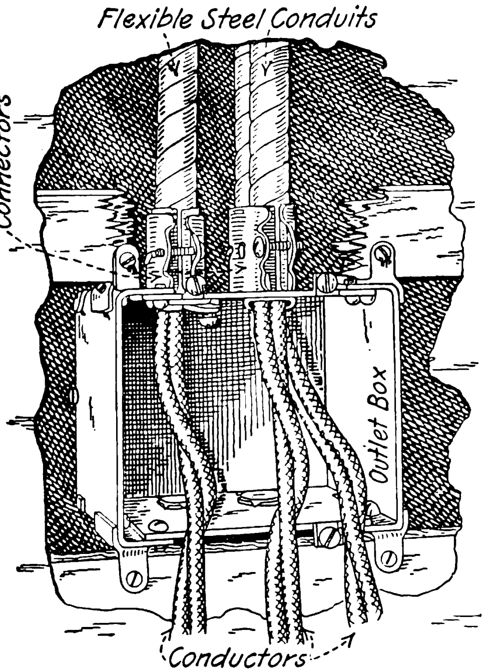


FIG. 182.—Flexible steel conduit outlet box.

240. To cut flexible steel conduit a fine hack saw should be used. Special vices can be purchased which have a slot across their jaws to guide the saw blade, the conduit being held between grooves in the jaws.

241. For reaming flexible steel conduit a special reamer (Fig. 183) has been made but inasmuch as the burr resulting from the hack-saw cut is very small, it can be readily removed with a three-cornered scraper made from a three-cornered file or with an ordinary file. The reamer illustrated is for conduit of $1\frac{1}{4}$ in. or less diameter.

242. Fish plugs for pulling in flexible conduit (Fig. 184) are furnished by the conduit manufacturer for $\frac{3}{8}$-in., $\frac{1}{2}$-in. and $\frac{3}{4}$-in. double and single flexible conduit. After the conduit has been cut off square in a vice with a hack-saw the fish plug is screwed into the tube and the fish or drawing-in wire attached to the plug for pulling in.

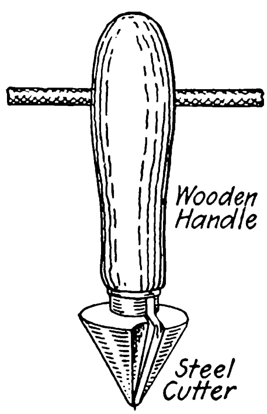


FIG. 183.—Reamer for flexible conduit.

243. Flexible steel armored conductor (Fig. 185) (*Standard Handbook*) consists of rubber-covered wire protected from injury and to a certain extent from dampness by two layers of flexible steel armor. The cable may be obtained leaded or unleaded, both being protected with the steel armor. The leaded cable differs from the unleaded in that it has a lead covering between the wire and steel armor to protect it from excessive dampness. Both the unleaded and leaded cables are made with single and multiple conductors of almost any gage wire. The leaded armored cable is approved and can be used for all classes of work, open or concealed, in fire-proof or non-fire-proof buildings, and during or after construction. The unleaded cable is approved

and can be used, open or concealed, in non-fire-proof buildings provided they are not subject to moisture.

The proper way to install armored cables in new buildings is to bore holes in the joists and partitions and to lace the cable in the same manner as wires in concealed knob-and-tube work; but it should always be looped from outlet to outlet. Where the cable is placed in slots nails are liable to be driven into it and not being nail-proof, it must be protected at such points with 0.125-in. iron plates. None of the cable should be installed until the roof and floor are in position. In running between joists and at outlets

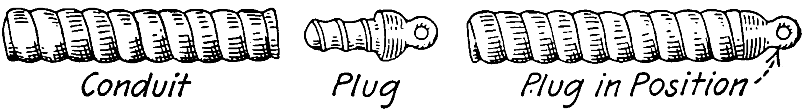


FIG. 184.—Plug for pulling-in flexible conduit.

the cable should be securely fastened if possible with pipe hooks or straps, so that in case the lock-nuts or bushings should fall off at outlets, the fastenings will prevent the cable from pulling out of the box and becoming lost between the joists or studs.

The wires should extend about one-half a foot beyond the outlet box in order to permit the proper connection of fixtures and switches, In some cities unleaded armored cable is not permitted to be plastered in brick walls or on metal partitions; but where allowed it should be cemented in place and allowed to stand several days before the walls are plastered so that the cable will be protected

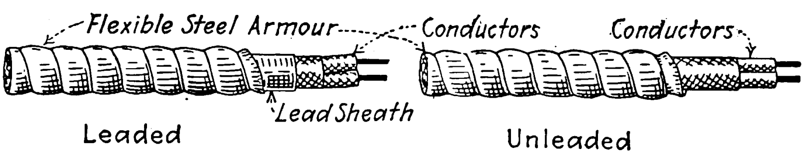


FIG. 185.—Steel armored conductors.

from the dampness caused by the wet plaster. The unleaded cable should not be run under tile or cement floors until after these have been laid because of the dripping water. Armored cable is the best substitute, not including rigid conduit, for concealed knob-and-tube work and also for molding work.

244. Manipulating Flexible Steel Armored Conductor.—It should never be spliced except at outlets. Many methods of fastening cable in outlet boxes are in vogue. Outlet bushings are very widely used. Outlet and switch boxes specially adapted for flexible armored cable are on the market. Many special cutters are on the market. The armor should be cut square so as not to leave sharp corners which cut into the insulation of the wires.

245. Steel Armored Conductor for Old Building Wiring.—It can be used to great advantage in this work. An advantage possessed by it is that it can be run with almost utter disregard to its contact with pipes or other materials and can be fished for long distances. Its own weight is sufficient to carry it down partitions

and it is stiff enough to fish between joists without the use of a fish wire. It can also be installed quicker and with less cutting of walls, floors, etc., than can wires in flexible tubing or concealed knob-and-tube work, and although a trifle more expensive, it makes a better job. Care should be taken in setting outlet boxes not to depend on laths to hold them because almost invariably in

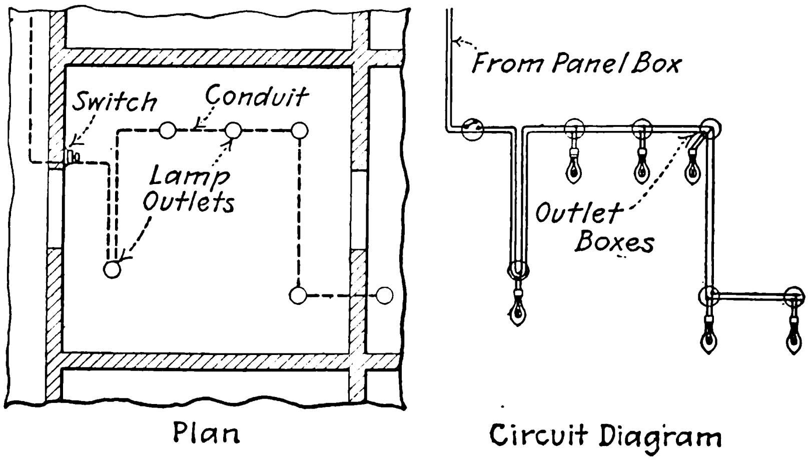


FIG. 186.—Loop system of conduit wiring.

hanging and straightening fixtures, they are pulled loose if not securely fastened to a joist, stud or backboard. Fixture stems should be fastened to boxes with stove bolts, riveted over the nuts.

246. The sheaths of flexible steel conduit and of flexible steel armored conductors must be grounded. The methods used for grounding are similar to those for rigid conduit which are described

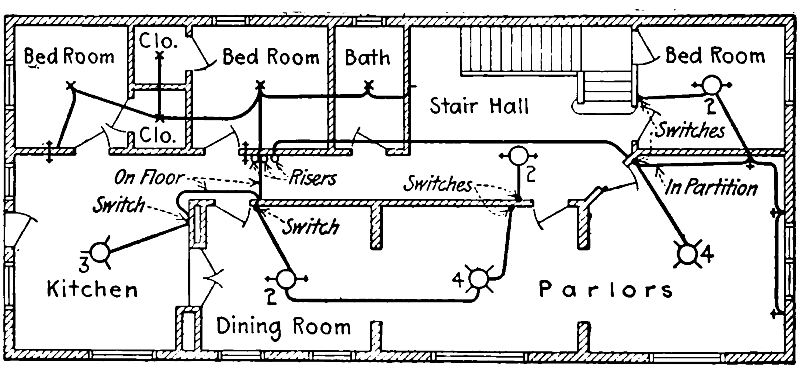


FIG. 187.—Example of loop system of wiring in a flat.

on another page. Suitable clamps which are required hold the steel sheaths in position in outlet boxes, serve to complete an electrical connection through the box. Where a group of these flexible steel armored conductors or conduit enters a wooden panel box all of the sheaths must be bonded together with a copper wire, No. 4 or larger, soldered to them, which connects to ground.

247. The **loop system of wiring** is nearly always used where conduit is concealed. (See Figs. 186 and 187.) The conductors loop to each outlet and the use of junction boxes is thereby avoided. Splices should be made only in junction boxes and the boxes should always be available for inspection.

ELECTRIC LIGHT WIRING

248. The maximum incandescent lamp load permissible on any branch circuit is, except in special cases, 660 watts. That is, wiring should ordinarily be so arranged that no set of incandescent lamps requiring more than 660 watts (16 sockets), whether grouped on one fixture or on several fixtures or pendants, will be dependent on one cut-out. Permission may be given in special cases, for departures from the rule. Although a branch circuit feeding ten 66 watt lamps would satisfy the requirements, it is not usually the practice to connect more than 8 or 12 incandescent lamp outlets to any one branch.

Gas-filled lamps to a capacity of 1320 watts (32 sockets) may be dependent on one cut-out *provided* No. 14 wire is carried directly into the keyless sockets or receptacles.

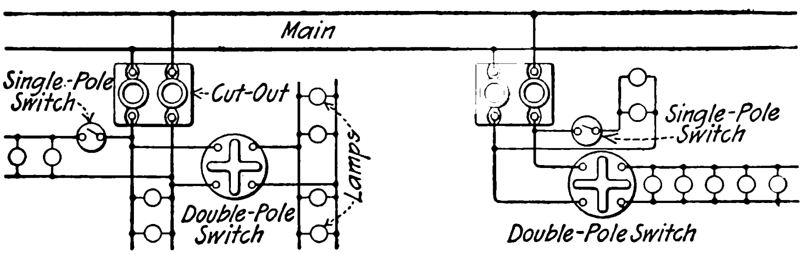


FIG. 188.—Connections of lamps to circuit.

249. The Connection of Lamps to Circuits.—The principles outlined in Fig. 188 are general. The lamps on the circuit extending vertically downward from the cut-out at the left of the illustration would burn as long as the main was alive. The other lamps are controlled by either single-pole or double-pole switches. Single-pole switches should not be used for the control of loads exceeding 660 watts. Three-way switches are considered the equivalent of single-pole switches in this respect.

250. Panel-box panels are illustrated in Figs. 189, 190 and 191. A panel provides a means of connecting (through fuses) the branch circuits to a main. Switches may be used as in Fig. 189, in both the main and branch circuits, or switches may be omitted, as in Fig. 191. Whether or not switches should be provided, is determined by conditions. Many satisfactory installations are in operation without switches, but switches are of great convenience for opening the circuits, for replacing fuses, or for testing. In general, knife switches in branch circuits should not be used for throwing on and off lights, as they are not usually of sufficiently strong construction to stand up long in such service.

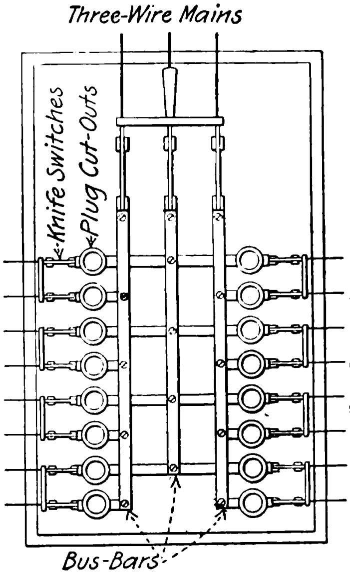


FIG. 189.—Three-wire distributing panel.

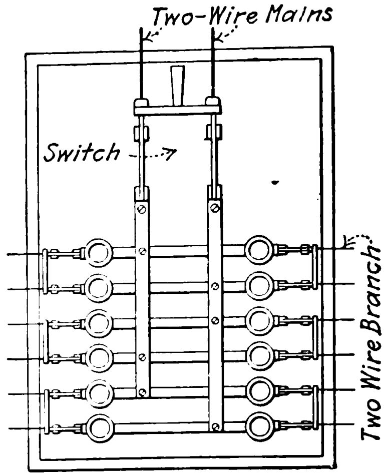


FIG. 190.—Two-wire distributing panel.

Branch lighting circuits should be controlled by either flush or surface snap switches, mounted outside of the panel box. See index for further information on panel boxes.

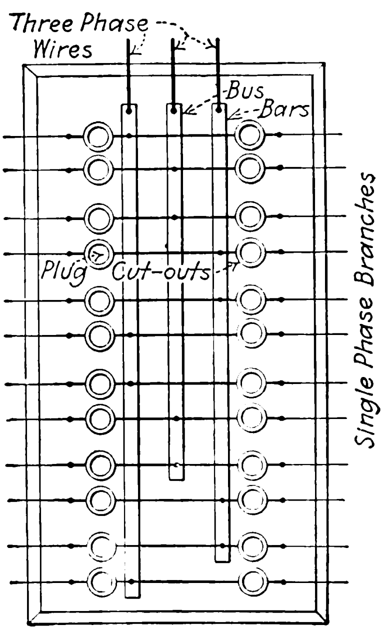


FIG. 191.—Three-phase to single-phase distributing panel.

251. **The method of controlling a group of lamps from either of two locations, with snap or flush switches,** is shown in Fig. 192. Two special "three-way" switches, of either the flush or surface type which can be readily purchased, are required. This scheme of wiring is much used for hall lights, so they can be controlled from either the first or second floor. Either of the schemes of wiring described in connection with Fig. 192 may be employed.

252. **The method of controlling a group of lamps from either of two locations, with knife switches,** is shown in Fig. 193. The method of *I* is preferable if both switches are near the lighting circuits, because it is economical of wire. If both switches are far from the lighting circuit, the method of *II* may be preferable. Where one of the switches is far from the

circuit, there is not much choice. In any case where there is a question, draw diagrams approximately to scale, and which method is preferable will be evident. The method of *II* cannot be used with direct-current arc lamps, because throwing the switches will

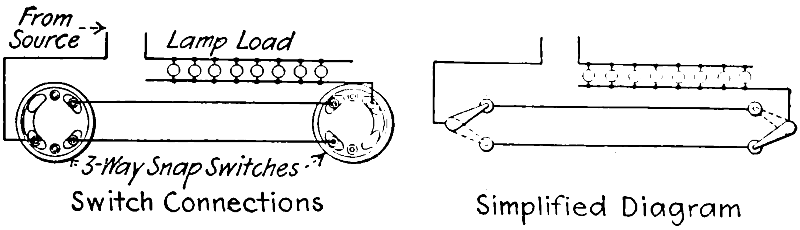


FIG. 192.—Circuits controlled from two locations.

reverse their polarity. Snap or flush switches are preferable to knife for two-location control, because a person may leave a knife switch open.

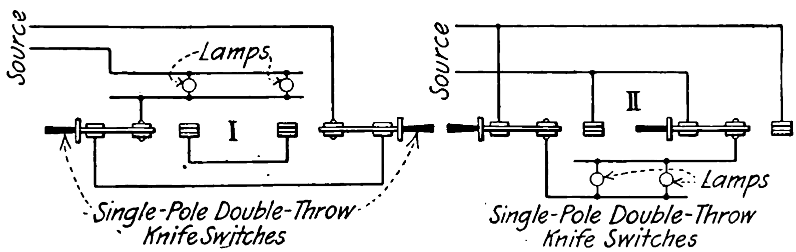


FIG. 193.—Circuit controlled from two locations with knife switches.

253. Two-location control with double-pole switches is shown in Fig. 194. This or some similar method must be adopted where the load exceeds 660 watts, as a greater load than this should not be controlled with single-pole switches.

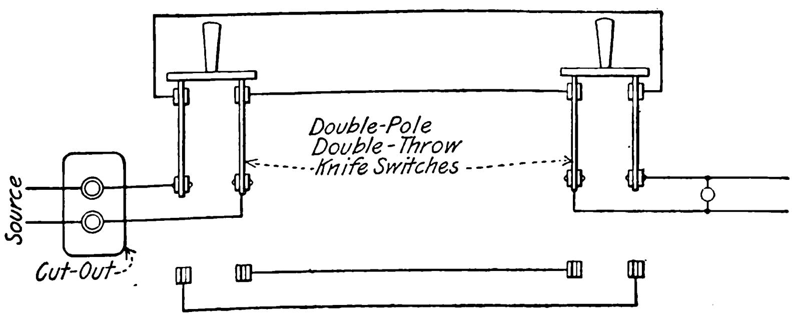


FIG. 194.—Double-pole-switch, two-location control.

254. The method of controlling a group of lamps from any one of more than two locations, with flush or snap switches, is shown in Fig. 195. Special switches made for the purpose are required. A "three-way" switch is used at each end of the circuit, and as

many additional "four-way" switches are necessary as there are additional control locations. This method is also much used for wiring for hall lights, so that all can be controlled from any floor.

255. **For controlling a group of lamps from any one of more than two locations with knife switches,** the wiring of Fig. 196 may be used. One single-pole, double-throw, knife switch is required for the two end locations and as many additional double-pole,

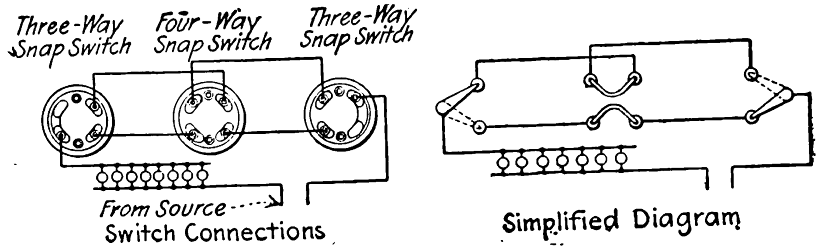


FIG. 195.—Circuit controlled from three locations.

double-throw switches are required as there are additional control locations. As above noted, knife switches have the disadvantage that one may be left open and interfere with the operation of the circuit.

256. **An emergency or burglar circuit** is shown in Fig. 197. This arrangement can be used where it must be possible to light certain lamps in a building from a certain location, irrespective of whether the switches normally controlling the lamps are closed

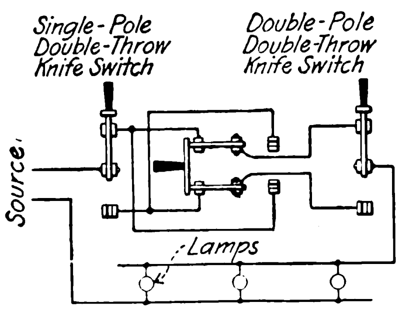


FIG. 196.—Circuits controlled from three locations with knife switches.

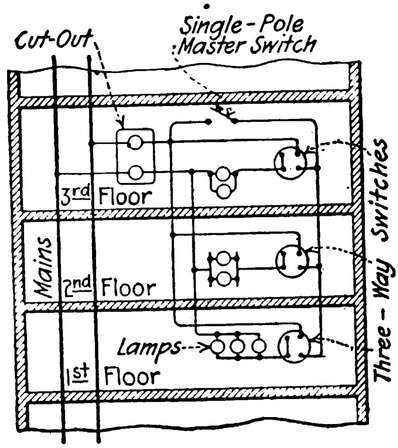


FIG. 197.—Emergency circuit.

or not. The master switch is usually located in the owner's room, so that he can illuminate the house in case of fire, an invasion by burglars, or other emergency. The method shown cannot be used for an installation involving more than 660 watts' capacity of incandescent lamps, because this is the maximum capacity that is permitted on a single-pole switch. Where a load of more than 660 watts is involved, two or more single-pole master switches can be applied, and each used for an independent emergency circuit;

or a double-pole or triple-pole switch can be installed and each pole used for an independent circuit. In some cases to control hall lights, it is necessary to substitute "four-way" for "three-way" switches. Fig. 198 shows a method of arranging an emer-

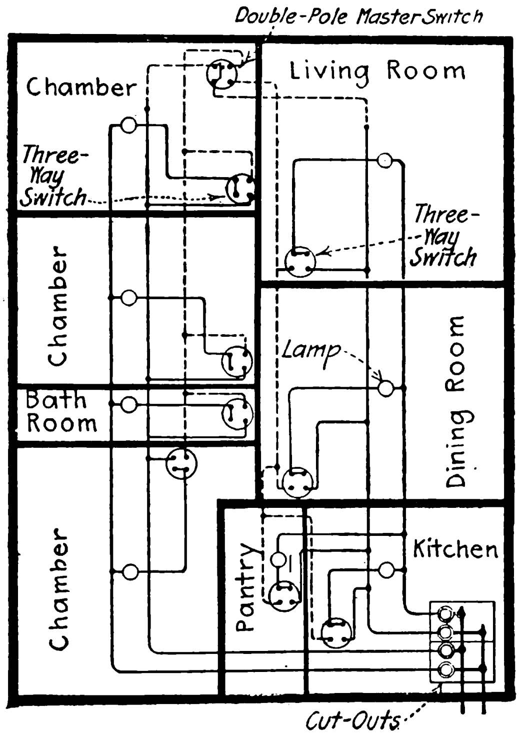


FIG. 198.—Emergency switch wiring in an old building.

gency switch in a building that has already been wired. The dotted lines represent the wiring that should be added to the existing wiring, to provide for the emergency switch feature.

257. Electrolier switches for controlling lamps in groups,

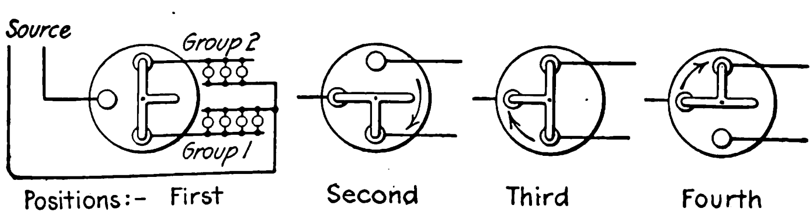


FIG. 199.—Two-circuit electrolier switch.

which control is often necessary in room lighting where there is a dome or electrolier having several distinct circuits, are wired as shown in Figs. 199 and 200. Special snap switches, which are made of either the flush, pull, or surface type, are necessary. With

the two-circuit switch, Fig. 199: With the switch handle in the first position all lamps are off—in the second position only those of *group* 1 are on—in the third position those in both groups are on—in the fourth position only those in *group* 2 are on. Then with the next quarter turn of the switch the first position is again assumed and all lights are extinguished. While the same principle is always used, all commercial electrolier switches are not arranged exactly as illustrated.

For controlling three groups of lamps, a three-circuit switch, Fig. 200, is used. It is not possible to illustrate the operation of this switch with a simple diagram, and different makes operate differently. With one kind the operation is as follows: First turn connects *group* 1; second turn connects *groups* 1 and 2; third turn connects *groups* 1, 2 and 3; fourth turn disconnects all lamps.

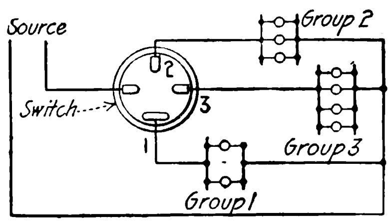


FIG. 200.—Three-circuit electrolier switch.

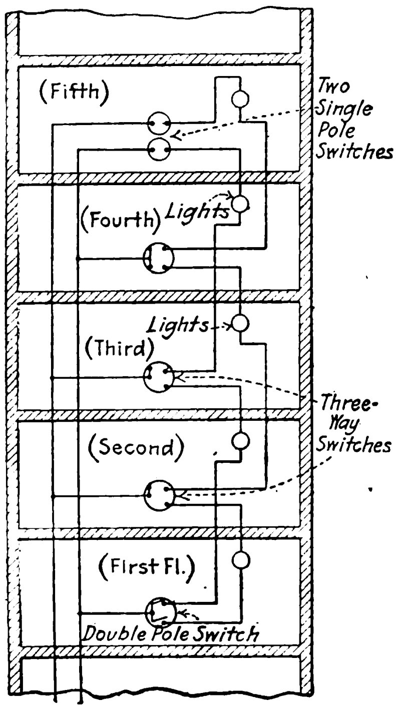


FIG. 201.—Stairway wiring.

258. A circuit arrangement for stairway lighting is shown in Fig. 201, whereby one can illuminate the landing that he is on and the one above or below him, as he goes up or comes down the stairs. The switch at each landing must be operated in passing. Two single-pole switches are shown on the fifth floor. With the two switches the lamp on that floor can be left burning if desired. Simpler arrangements than that shown are possible, but with them when a person turns a switch, the lamp on the floor on which he is, is extinguished as the one ahead is lighted.

CRANE WIRING

259. Cranes collect their current by means of trolley wheels or shoes which bear against copper trolley wires or structural steel conductors that are erected parallel to the crane runway. The location of the conductors is determined by conditions. Sometimes the crane builder specifies that the conductors must be located in a certain position; and in other cases the purchaser selects and specifies the position of the conductors and the crane manufacturer

arranges the current collectors on the crane accordingly. Probably the best location for the collector conductors on a bridge crane runway, is between the flanges of and parallel to one of the crane girders. Here the conductors are out of the way, well protected and can be readily supported. It is not often that they are erected in any other position. Occasionally the trolley wires can be supported from the roof trusses above the crane runway, and are installed similarly to the trolley wires for trolley cars. A pole collector with a wheel at its upper end, exactly like a trolley car pole but much shorter, is used. Where the spacing between roof trusses is very great this method may not give good results, because of the wire swinging and the trolley coming off. (Much of the following material on Crane Wiring is from an article on that subject, which was written by the compiler of this book and printed in *American Machinist*, Oct. 17, 1912, under the pen name of Ernest G. Bradshaw.)

260. Trolley wire for cranes is hard drawn copper, the same as used in electric traction. Hard drawn wire must be used to prevent excessive stretching. Round wire is erected where the method of support adopted does not involve the use of trolley ears for holding it at intermediate points between the ends of the run. Where trolley ears are used "Fig. 8," or preferably, grooved trolley wire should be used, because they can be readily held in screw-clamp trolley ears. Round wire can be used with trolley ears, but the ear flanges of these must be hammered down around the

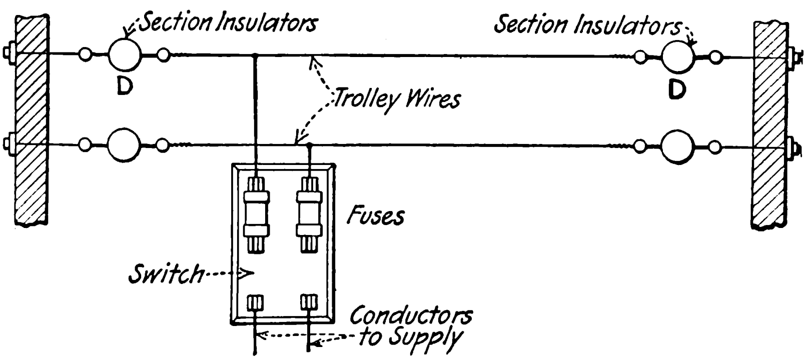


FIG. 202.—Crane wiring service switch.

wire, a time consuming operation requiring some skill; also, a round-wire ear introduces a hump on the wire and makes the trolley wheel jump and draw an arc when the wheel passes over the raised place. Either 0, 2/0, 3/0 or 4/0 wire is usually required. The wire size required is ordinarily specified by the crane builder, but in any case it should be large enough that the voltage drop in it will not much exceed 3 or 4 per cent. of the line voltage with all of the crane motors operating at full-load.

261. A crane service switch (Fig. 202) should be installed for feeding every crane circuit. A fused switch is most frequently used to provide overload protection, although in important in-

stallations, where reliability is essential—where equipment must be placed back in service after an accident, in minimum time—circuit-breakers are used. From an electrical standpoint, the best location for the service switch is at the center of the run. In practice, however, it should be placed where it can always be reached from a ladder running to the floor and so the operator can open his circuit when he leaves his machine.

262. Methods of supporting crane trolley wires differ with conditions. If the crane is provided with hook-shoe collectors (Fig. 203), which slide along under and carry the weight of the trolley wire, the wire is rigidly held only at the terminations at the ends of the run, and is kept from sagging by intermediate, insulating brackets, like those shown in Fig. 203. If trolley wheel current collectors are used (and they probably provide the best means of collecting current), the tension in the wire is taken by the terminations, and the wire is also rigidly held by trolley ears at intermediate points.

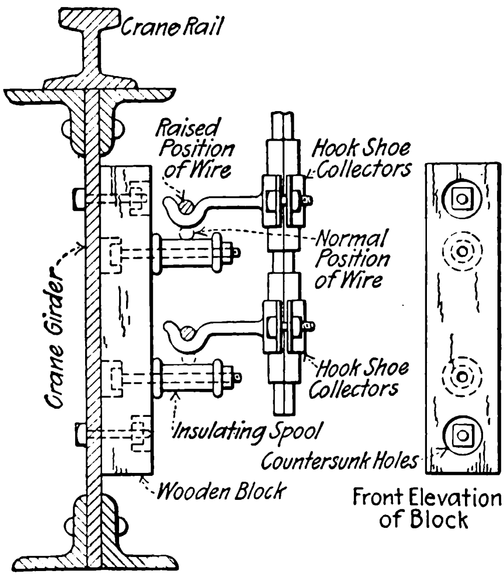


FIG. 203.—Intermediate bracket for trolley wire.

263. Terminations are made as shown in Fig. 204. Strain insulators separate the trolley wire electrically from the building members, and either a turnbuckle, or an eye-bolt with a long thread, can be used for pulling the slack from the wire and adjusting its tension. The terminations should be depended upon to assume the entire tension of the wire. The intermediate supports are placed merely to prevent excessive sagging. The members which take the stresses of the eye-bolts at the terminations should be very substantial, or thoroughly braced, because on them depends the reliability of the entire installation. The eye-bolts, turn-buckles and strain insulators should be not smaller than the $\frac{5}{8}$-in. size.

264. Intermediate supports for crane trolley wires, the supports installed between the terminations to prevent sagging, can be arranged as shown in Figs. 203, 205 and 206. The bracket of Fig. 203 is, as above outlined, applicable only where the crane has hook-shoe collectors. The block of wood that supports the insulating spools should be thoroughly dry and treated with an insulating paint. The bolt holes in it should be deeply countersunk, to eliminate the possibility of grounds. The spools can be of dry, painted wood—where the Underwriters will permit—but should be

of porcelain. Porcelain tubes with porcelain knobs at the ends to form flanges will do. The length of the insulator between flanges should be at least 4 in. Spools turned from fiber are sometimes used. The spools should be so arranged that there will be at least a ½-in. clearance between them and the hook-shoe when it passes along.

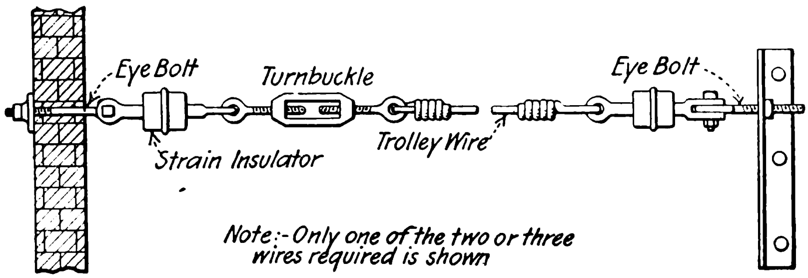


FIG. 204.—Trolley supports at ends of run.

In a fire-proof building, where the crane has trolley wheel collectors, the wires can be supported by trolley ears as in Fig. 205. The wooden supporting block must be thoroughly painted and the bolt holes in it deeply countersunk, to prevent the possibility of grounds. Tap bolts, screwing in from the rear, support the screw-

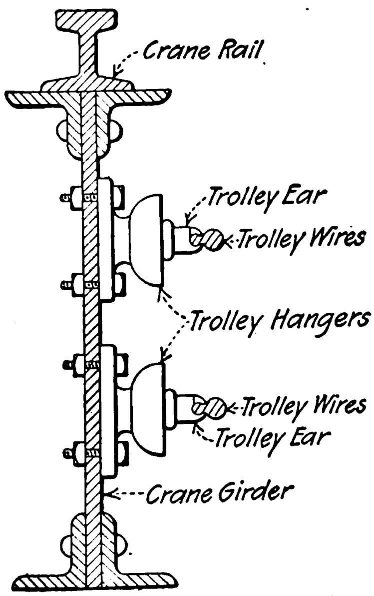


FIG. 205.—Trolley ear supports.

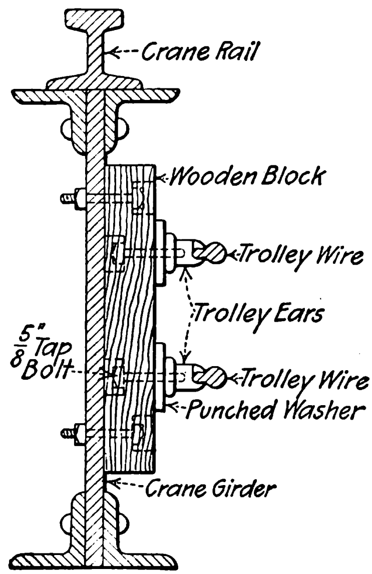


FIG. 206.—Trolley hanger support.

clamp trolley ears which seat against washers. "Figure-8" or, preferably, grooved trolley wire is used. The wire should be drawn tightly at the terminations and the ears should be installed every 8 or 10 ft.

For an out-door crane, or for applications where the Underwriters have jurisdiction, the wires can be supported as shown in

Fig. 206. Standard street railway type trolley hangers and ears are used, which provide excellent insulation. The hangers can, provided a proper location of the trolley wires results, be bolted directly to the crane girder.

265. **Trolley rails of structural steel** are being used to some extent instead of copper trolley wire to supply current to cranes and other moving electrical machinery. The steel rails are made sufficiently heavy that they cannot break and fall as copper wires occasionally do. Sometimes strap steel bars are used, but more frequently a section is adopted, such as an angle or a tee, which has considerable stiffness in all directions. Steel conductors should be painted, except on the contact edge or face, to prevent corrosion. Either a shoe or a trolley wheel can be used to collect current from a steel conductor rail. A shoe or spoon, which makes a rubbing contact, is probably preferable for the average application. Trolley-wheel collectors that travel at high speeds are not successful for current collection from steel conductors, because the wheel tends to bounce and jump from the rigid rail at joints and uneven places. There are almost numberless ways in which steel conductor rails can be arranged and supported. The arrangement described in the following paragraph is typical.

266. **An installation of a structural steel tee conductor or trolley rail** is shown in Fig. 207. While the arrangement illustrated was developed for serving mono-rail cranes, which travel on the lower flanges of I-beams, only minor modifications in the supporting forging would be required to adapt it for serving bridge cranes or other similar traveling electrical machines. Note that a feature of the method is that no drilling or close fitting is required in the field. The only piece that is different for different jobs is the supporting forging, but this can be formed and drilled in the shop. The only tools required to erect the rail are a hack-saw for cutting the tee, which is purchased in 30-ft. lengths, and a wrench for setting the bolts. No bolt smaller than $\frac{5}{8}$-in. diameter is used, because smaller ones than this can be twisted asunder too easily. A tee $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. in dimensions was selected, because this is about the smallest size that is rigid enough to effectively sustain itself between supports. A tee of this size has a conductively equivalent to that of a 109,800 cir. mil copper conductor, that is, a copper conductor between No. 0 and No. $\frac{2}{0}$ in size.

The insulating hanger (Fig. 207, *II*), is similar to a trolley hanger, but smaller. A mallable iron bell encloses the molded material that supports and insulates the hanger stud. The Johns-Manville Company makes the insulator to special order and its mold number is 4689-B. The splicing plate (*IV*) and the clamp (*V*) are castings, preferably malleable iron, and the only machine work on them is the drilling and tapping of the holes. The section insulator (*VI*) consists of two castings, a fiber dividing-block and two wrought-iron clamping plates. Directions for spacing the insulating supports when erecting the conductor are given on the illustration. The terminal lug (*VIII*) is forked instead of annular, so that it can be readily disconnected for isolating circuits for testing without taking out a bolt.

267. **In computing the resistance of steel trolley rails,** the area in square inches, of the section involved, can be taken from

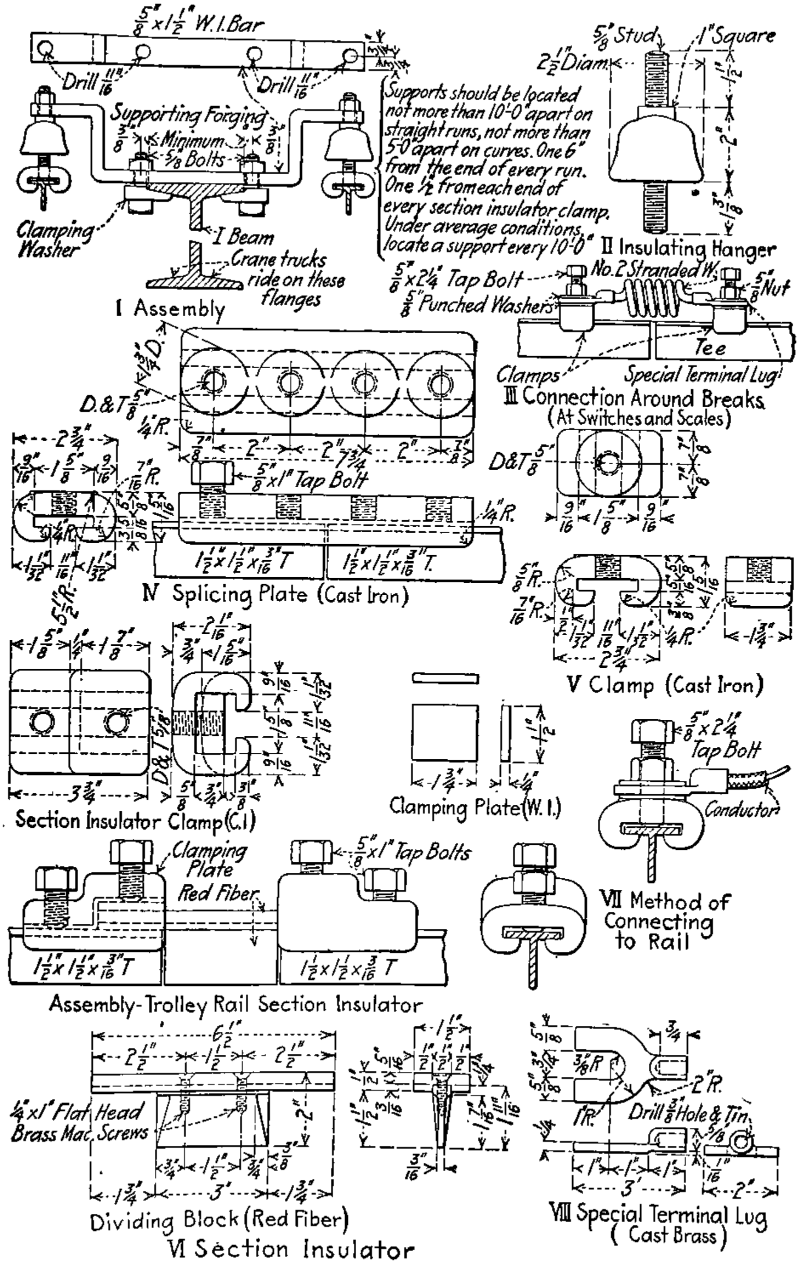


FIG. 207.—Steel trolley rail.

one of the steel company's handbooks, such as are issued by the Cambria and Carnegie steel companies; the area in cir. mils can

then be obtained by using the rule given below. By dividing this area by 6.14, which is the approximate ratio of the resistance of mild steel to that of copper, the equivalent copper area of the steel conductor results. Then by using the standard formula for the resistance of a copper conductor, the actual resistance of the steel is obtained.

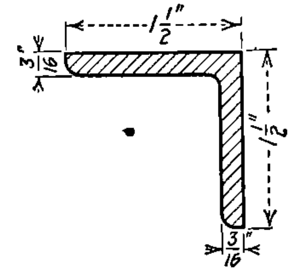


FIG. 208.—Section of $1\frac{1}{2}$ in. $\times$ $1\frac{1}{2}$ in. $\times$ $\frac{3}{16}$ in. steel angle.

Example.—What is the resistance of 160 ft. of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. steel angle? (See Fig. 208 for a picture of the section.)

Solution.—By referring to a handbook, it will be noted that the area of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. steel angle is 0.53 sq. in. Then to find its area in cir. mils:

$$\text{cir. mils} = \frac{\text{area in sq. in.}}{0.0000007854} = \frac{0.53}{0.0000007854}$$
$$= 674{,}800 \text{ cir. mils.}$$

Then:

$$\text{equivalent in copper} = \frac{\text{cir. mils area of steel}}{6.14}$$
$$= \frac{674{,}800}{6.14} = 109{,}800 \text{ cir. mils.}$$

Then the resistance of the 160 ft. length will be:

$$\text{Resistance (for copper)} = \frac{11 \times \text{ft.}}{\text{cir. mils}} = \frac{11 \times 160}{109{,}800} = 0.016 \text{ ohms.}$$

The resistance, therefore, of 160 ft. of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. steel angle is 0.016 ohms. It is evident from the equivalent copper area of the steel (109,800 cir. mils), that the conductivity of the steel section will lie between the conductivities of No. 0 (105,500 cir. mils) and No. 00 (133,100 cir. mils,) copper wire.

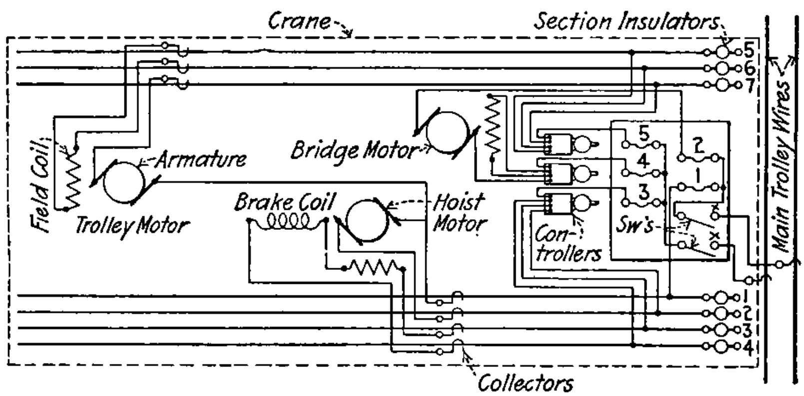


FIG. 209.—Direct-current crane wiring diagram.

The equivalent copper area in cir. mils can be used in any of the wiring formulas for computing drop in a steel conductor, just as the actual area of a copper conductor is used in the same formulas, and the result will be a correct one for the steel section. Obviously the above method is approximate, because the constants are approximate, but it is quite accurate enough for wiring computations which always involve necessarily inaccurate assumptions.

268. A crane wiring diagram is given in Fig. 209, which is typical for a direct-current, three-motor, traveling bridge crane. Variations in crane wiring and control schemes are practically number-

less. For direct-current cranes, series motors are almost invariably used, while for alternating-current cranes, wound rotor motors are used.

SIGNAL WIRING—BELL, ANNUNCIATOR, BURGLAR-ALARM, TELEPHONE AND ELECTRIC GAS LIGHTING WIRING

269. Brief of Underwriters' Rules Covering the Installation of Telephone, Call Bell, and Similar Circuits (*Factory Mutual Wiring Rules*).—The arrangement of these wires should be as carefully planned as that of the lighting or power circuits. They should be so placed as never to be in the way of fire streams or ladders. Where possible, the signal wires about the yard should be kept entirely away from lighting or power circuits. This avoids the liability of the two systems crossing if breaks occur and of dangerous currents being conducted into buildings over wires ordinarily considered harmless. Where the arrangement is of necessity such that crosses might occur if wires broke, protectors should be provided near the point where the signal wires enter each building. Protectors should also be provided on all foreign lines, such as public telephone or fire-alarm wires, and on all private lines which are liable to receive lightning discharges.

Where signal circuits are operated from electric-lighting or power circuits with or without lamps or other resistors in series, the signal circuits must be insulated on porcelain and the same construction followed as for lighting circuits. The bells and buttons or switches must be of non-combustible materials and held away from the supporting surface with porcelain knobs.

No signal wire should be closer than 2 in. to any electric light or power wire unless additionally insulated therefrom by some firmly fixed non-conductor such as a piece of flexible tubing or, preferably, a porcelain tube.

270. In installing signal wires in finished buildings the rubber-covered twisted pair copper wires may be used. They may be run along the top of the baseboard or along the picture molding. Where it is desirable to conceal the wiring and where expense is no consideration, the wires may be fished like lighting wires in concealed work. Where wires are bunched together in a vertical run, a fire-resisting covering sufficient to prevent fire from traveling from floor to floor, must be provided. Signal or telephone wires cannot be run in the same conduit with lighting wires. (The material that follows on Signal Wiring is largely from a series of articles on that subject, by the compiler of this book, printed in *Popular Electricity* during 1912 and 1913.)

271. Signal wires may be supported on wood in dry places with metal staples (Fig. 210) driven into the timber. Never fasten more than one wire under a staple, unless the wires are first protected with a tape wrapping. In damp places ordinary staples rust and eat through the insulation. Electrolytic action may ensue, whereby the wire will be eaten through. It is very difficult to drive round top staples in straight; hence staples having

square tops, of a style narrower than the ordinary double pointed tacks, should be used. Zinc coated staples are preferable to coppered ones. Insulating saddle staples (see illustration *II*), are probably as cheap in the long run as the ordinary metal ones, as two wires can be safely held under one saddle staple, and time is thereby saved. Insulating saddle staples secure the wire well at turns and prevent the metal from cutting into the insulation. In stringing a long run, a saddled staple at the end will hold the slack until the intermediate staples are placed.

272. Cleats of compressed, impregnated wood (see Fig. 210) are good for supporting a twisted pair conductor in an exposed place,

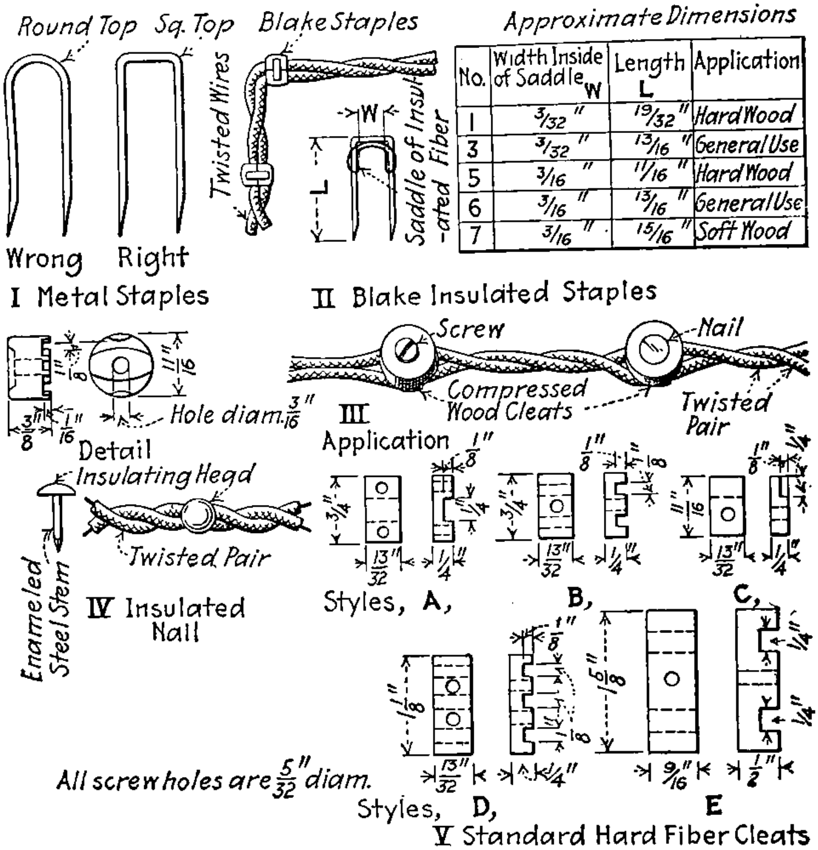


FIG. 210.—Fasteners for signal wiring.

as they are very neat in appearance. Either nails or screws can be used to hold them. The compressing of the wood prevents the cleats from splitting. They are particularly useful for runs over plastered surfaces, and in other places where staples cannot be used. When stringing long runs of wire, compressed wood cleats at the run ends will hold the slack until the intermediate cleats are placed. These wood cleats cost less than those of either porcelain or fiber. They can also be used to support single wires, one wire under a cleat.

273. **Insulated nails** (Fig. 210, *IV*) having a metal stem and a head of insulating material, are used for supporting twisted pair conductors, and while they are cheap, they do not support the wires as well as does the wood cleat. They do not hold a single wire well and do not properly hold back slack in long runs. The nails are made in different lengths and with heads of different colors to match surroundings.

274. **Hard fiber cleats** (Fig. 210, *V*) are used where one or more single conductors are to be supported, but are not as good as the wood cleats, although they cost more. It is sometimes necessary to use them where the wire supported is too large for the standard wood cleat.

275. **Wire for bell work** in dry places is usually No. 18 copper, double cotton covered and paraffined. Where more than two or three bells are connected to the circuit, or where the circuits are long, No. 16 wire should be used. No. 14 is frequently used for battery wires. Rubber covered twisted pair wires, like those used for interior telephone wiring by the telephone companies, can often be used to advantage in damp places or where the circuits are exposed. No. 20 wire, although sometimes used, is too small for reliable work. Annunciator and twisted pair wire is made with insulating coverings of different colors, so one can be selected that will match the surroundings, and, thereby, be inconspicuous. Cables of annunciator wire, which can be obtained with practically any number of conductors from 2 up to 200, are very convenient and economical for large installations. In perfectly dry locations, a cable having a paraffined, braided cotton covering can be used, but if it is to be exposed to dampness a lead covered cable should be installed. By having the cable conductors covered with braids of different colors, the conductors can be readily identified. A kind of weather-proof wire called "damp-proof," is quite satisfactory for exposed wiring in damp places. It is more expensive than annunciator wire, but it has a better appearance when installed.

276. **The installation of signal wiring in wooden framed buildings** requires great care. The conductors are so weak mechanically, so poorly insulated and there are frequently so many of them, that if work is not systematically and thoroughly erected, trouble invariably results. The wires can be supported in unfinished houses by fastening them to the studs and joists with staples. In finished houses wires can be run behind a base board or under the molding at its top; or by prying up a floor board the wires can be placed under it. A saw cut, into which the wires can be dropped, can be made in any joist that lies across the path of the wire. Wires can be run on the tops of picture moldings.

277. **In fishing for vertical wires** a piece of small chain 2 ft. long is attached to a length of strong cord. The chain and cord is pushed through a hole bored for the wire at the top of the partition, and the noise made by the chain when the cord is pulled up and down, will indicate the location of any obstruction. With the obstruction located, the baseboard or floor board can be taken out and a hole can be bored or some other means adopted to provide a pocket whereby the chain can be reached.

278. The steel fish bit (Fig. 211) is a useful tool in installing signal wires. The bit has a hole in its end. After the bit has been bored through an orifice, the wire to be drawn through is made up through the hole and the wire and bit are together drawn back through the orifice. The use of a fish wire is thereby eliminated. In a floor or ceiling, the orifice having been bored, it may be more convenient to first withdraw the bit and then to thread the wire through the hole at the end of the bit, and to push the bit back through the hole. Good bits of this type are so tempered that they will drill through wood, masonry, wrought iron or structural steel.

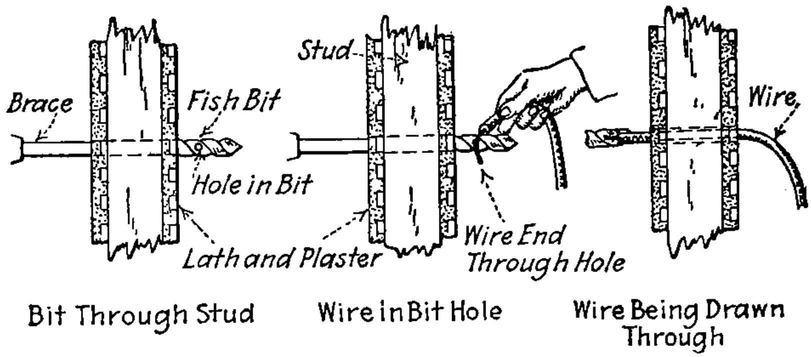


FIG. 211.—Use of steel fish-bit.

279. Electric bell circuits are shown in Fig. 212. Many of these are quite simple but are included so that all will be together for the electrician's reference. Two ordinary vibrating bells will not work well together in series, so, when it is necessary to connect two or more in series, one should be a single stroke bell, as in *IV*. A multiple arrangement *II* is preferable to a series arrangement, and the batteries for a multiple arrangement are more effective if connected in multiple. Try a series and a multiple arrangement of cells and ascertain which works best. Where several signal bells must be located together, gongs of different types (*VI*), each of which gives a different sound, can be used, In operating bells from an electric light circuit, incandescent lamps (*VII* and *VIII*) can be used for resistance. An ordinary bell usually requires about 0.1 amp. for its operation, and enough lamps should be used to cut down the current to this value. It is best to connect the bell in multiple with a lamp, as at *VII*, as thereby the arcing at the vibrating contact is minimized. At least one lamp should be connected in each side of the circuit at the cut-out, to prevent difficulties if a ground should occur on the bell circuit. Bells with platinum contacts are preferable for all services, but are expensive. A differential or short-circuiting bell (Fig. 215) can be used with good results, with lamps in series, on lighting circuits or high voltage battery circuits.

280. Return-call bell circuits for different services are shown in Fig. 213. With these, when a station is signaled, the party called can signal back by pressing his button. As a general proposition,

ground return circuits are undesirable, as one ground on one of the normally ungrounded wires may render the system inoperative; furthermore, there are often "stray" currents from electric railway circuits flowing in the earth, which may interfere with the operation of the bell circuits. With the arrangement of Fig. 213 *VII*, when the calling station is the one at the single stroke bell, the

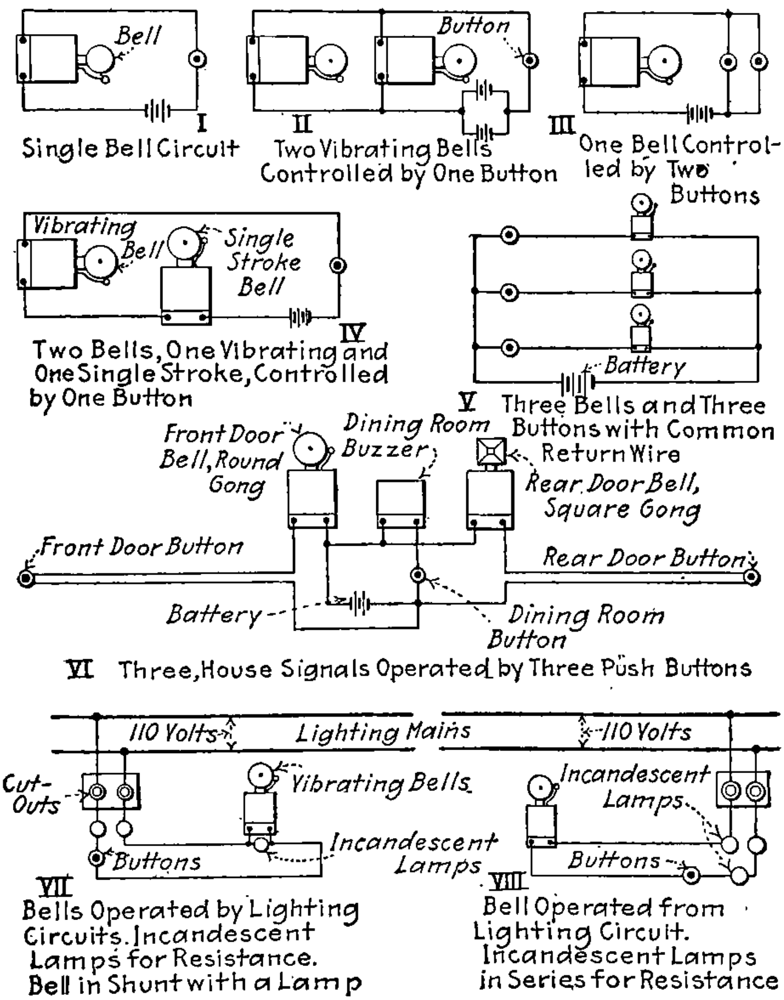


FIG. 212.—Elementary electric bell circuits.

caller may be sure that the called station is ringing, because it is the vibrating bell at that station that causes the single stroke bell to ring.

281. Apartment house and speaking tube bell wiring circuits are shown in Fig. 214. One battery serves for all stations. Frequently a larger sized wire is used for the battery wire, which supplies all of the stations, than for the other wiring.

282. Electric bells of different types are shown in Fig. 215. The vibrating bell is the one commonly used. The single stroke bell can be used in series with a vibrating bell, which will open and

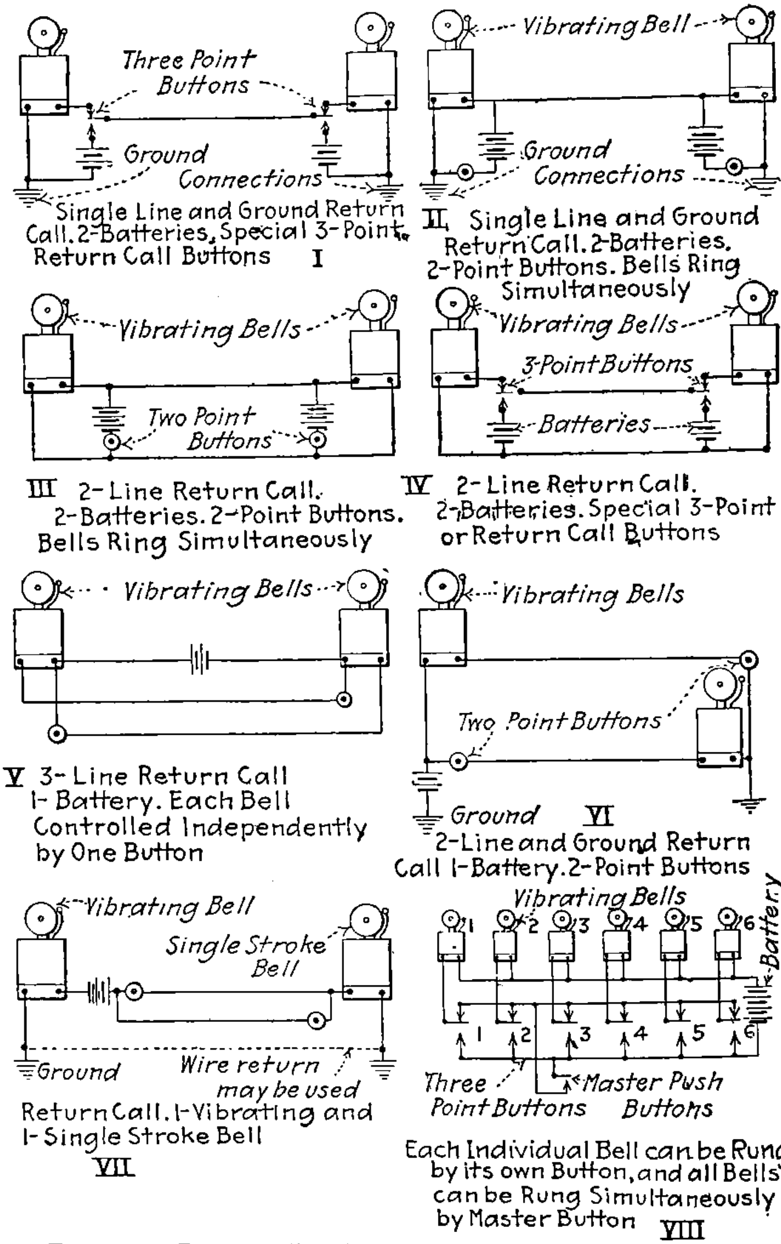


FIG. 213.—Return call and master button electric bell circuits.

close the circuit, and thereby make the single stroke bell also operate. It is essential for satisfactory operation, that the natural periods of vibration of the armatures and tappers for both bells,

be the same. If the armatures, tappers and springs of both are the same in weight, dimensions and construction, the natural

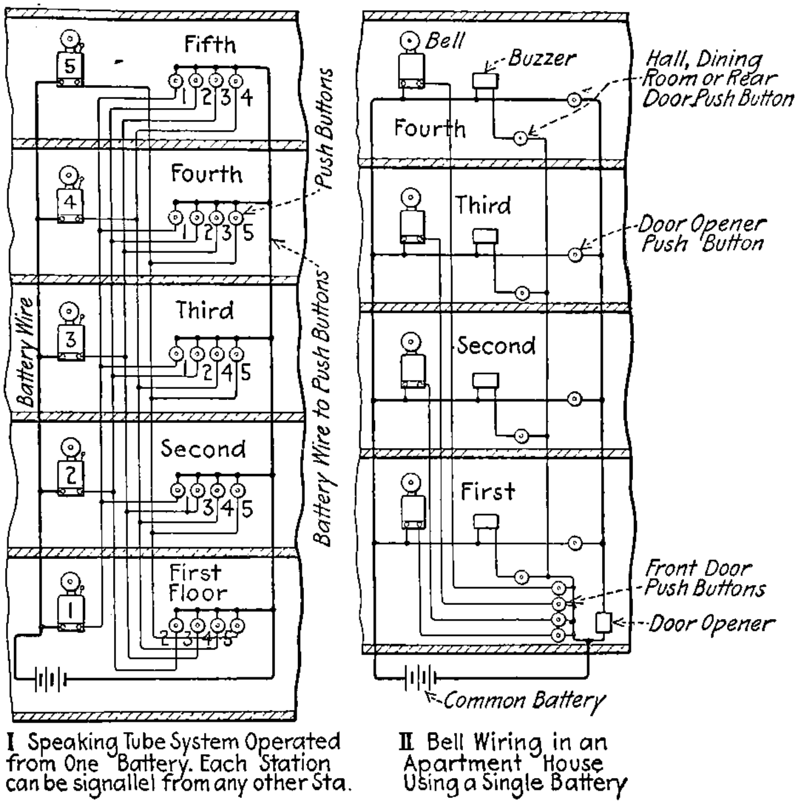


FIG. 214.—Apartment house bell circuits.

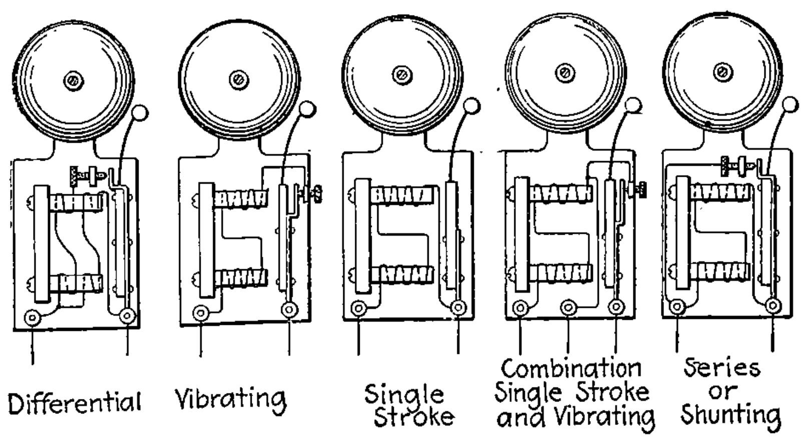


FIG. 215.—Electric bells of different types.

periods of vibration will be the same; small differences will not appreciably affect satisfactory operation. A vibrating bell can

be changed into a series bell by so adjusting the vibrating contact screw that the circuit will not be opened when the armature is drawn over.

283. **A combination single stroke and vibrating bell** is a combination of a vibrating and a single stroke bell, and can be used as either by properly connecting it. A two point switch can be arranged so that a bell of this kind can be made to operate at will, as either a single stroke or a vibrating bell.

284. **In series or shunting bells,** each time the armature is drawn over it makes a contact and short-circuits the magnets, thereby demagnetizing them; the armature spring draws it back and the operation is repeated. Bells of this type have been designed for use on circuits of voltages exceeding say 5 volts, to minimize arcing at the vibrating contact, but their operation has not been wholly satisfactory.

285. **In the differential bell,** the magnets are wound differentially, that is, so as to oppose one another. Hence, when the armature is drawn over by one magnet winding, it makes a contact

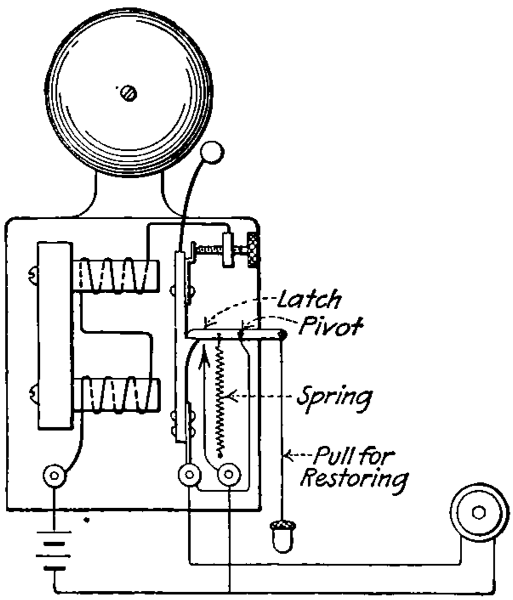


FIG. 216.—Continuous ringing bell.

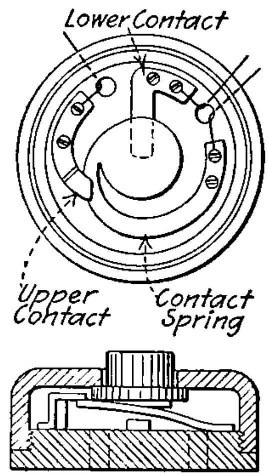


FIG. 217.—Double contact, three-point or return call push button.

which energizes the other winding, and, since the two oppose, the cores are demagnetized and the armature is drawn back by its spring. In operation this process is repeated so long as the circuit to the bell is closed. There is little or no sparking with a differential bell; hence it is used on circuits of relatively high voltage.

286. **A continuous ringing bell** (Fig. 216) is so arranged that when the button is pressed and the circuit closed through the bell, the armature is drawn over and the latch released and pulled down against its contact point by a spring or by gravity. This con-

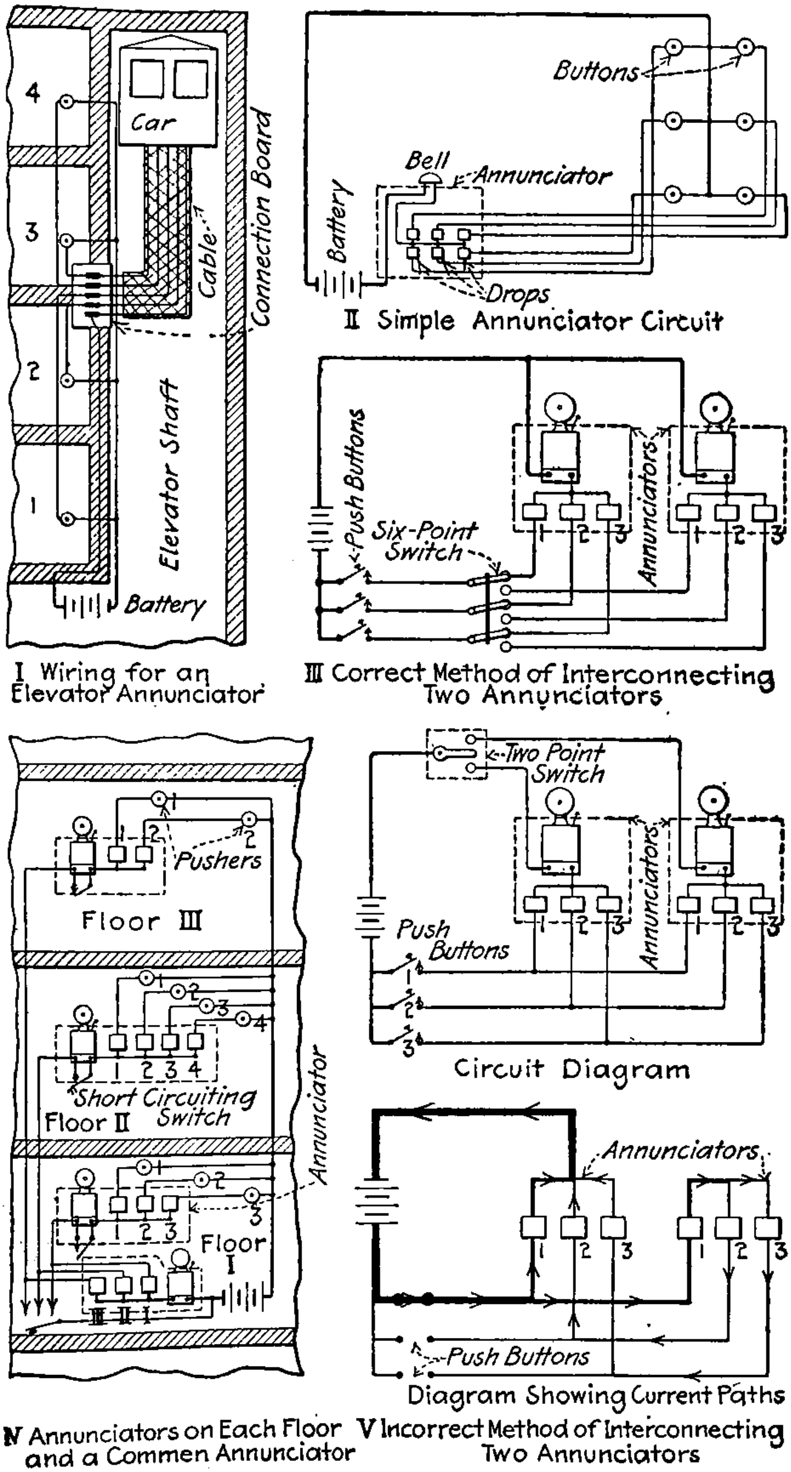


FIG. 218.—Annunciator circuits.

nects a shunt circuit around the button, and the bell continues to ring until the latch is restored by hand.

287. A double-contact, three-point or return-call push button (Fig. 217), is used in return-call bells and annunciator circuits. Applications of push buttons of this type are shown in the diagrams.

288. Annunciator circuits are shown in Figs. 218 and 219. With an elevator annunciator a cable having as many conductors as there are push buttons and one additional battery conductor is required. One end of this cable is attached to the car and the other is made fast midway up the elevator shaft and should be connected to the push-button wires with binding posts on a

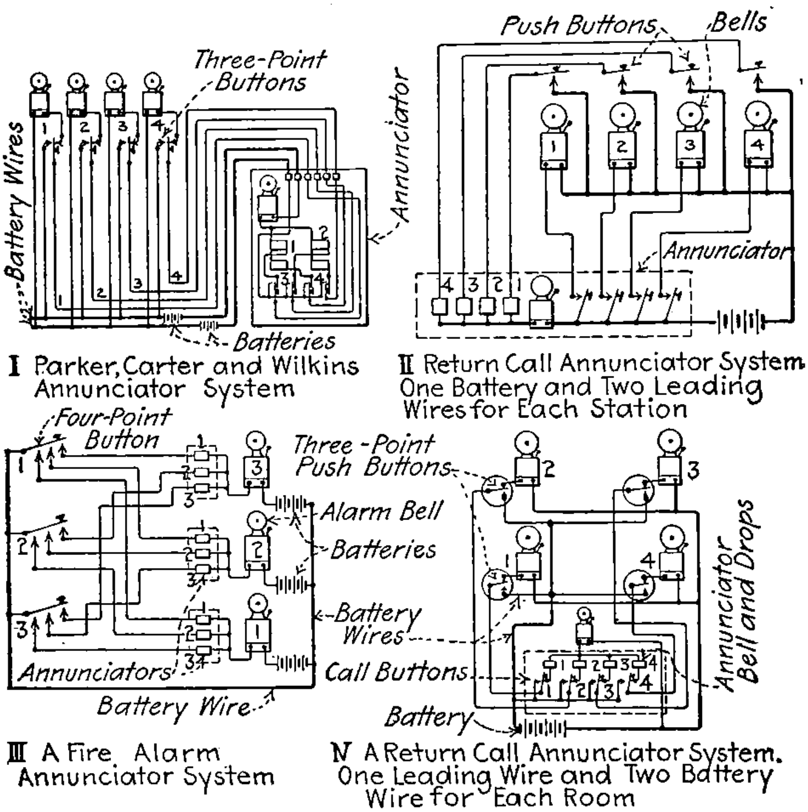


FIG. 219.—Fire alarm and return call annunciator circuits.

connection board. The connection board is of great convenience in locating trouble. It is a good plan to install a cable having one more conductor than is actually required so that a spare will be available in case of trouble.

Annunciators cannot be operated successfully in multiple because of the many paths that are afforded the signaling current through annunciators so connected. In Fig. 218 *III* is shown one correct method of connecting two annunciators installed at different locations and operated from the same buttons and battery. Either one or the other of the annunciators can be thrown into service

with the six-point switch. If two annunciators are to operate simultaneously the drops of one must be connected in series with the drops of the other. In *V* is shown an incorrect method of connecting two annunciators. With it, when one button is pressed there are several paths for the current and it will divide and flow as shown in the lower diagram and may, unless the annunciator adjustments and battery strength are just right, throw all of the drops. Annunciators connected in accordance with this method will ultimately give trouble.

The method of connection of *IV* is used where attendants are signaled from annunciators located in different parts of the building during certain periods of the day and from a centrally located annunciator at other times. Either the local annunciator bells or the common annunciator can be shunted out when necessary with the short-circuiting switches shown. Fig. 219, *I* shows a diagram of a Parker, Carter & Wilkins return-call annunciator system. With this system there is a considerable saving in wire as only one direct wire is required from a room to the annunciator. Two common battery wires are around the house.

Fig. 219, *II* and *IV* show two methods of accomplishing the same end. That of *II* is probably preferable for the average installation because (1) the signaling current does not pass through any button except that being pressed, (2) single-contact, not double-contact push buttons are used and (3) only one battery wire is carried to the rooms.

With the fire alarm system, *III*, when any one of the switches is closed all of the annunciator stations are signaled.

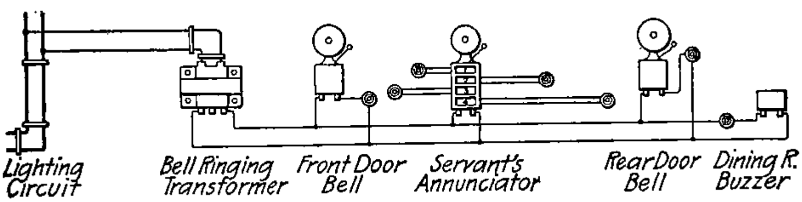


FIG. 220.—Application of a bell-ringing transformer.

289. Bell-ringing transformers (Fig. 220) should always, where there is alternating current, be used for operating signaling systems such as those for bell and annunciator service. A well-made bell-ringing transformer will last forever. Consult the local inspector as to his installation requirements before putting in a bell-ringing transformer, as there have been misunderstandings in regard to this matter. The Code Rules specify that the transformers shall be of special design and that the primary wiring shall be installed in accordance with the rules for light, power and heat wiring and that the secondary wiring shall be installed in accordance with the rules for signal system wiring. It is well to try out a bell-ringing transformer with any instrument that is to be operated by it, that has coils of many turns (such as an annunciator) before final connections are made, because the impedance of these coils to the alternating current sometimes "chokes" the current

and renders operation less satisfactory than would be expected judging from the secondary voltage rating of the transformer. A well-designed bell-ringing transformer requires practically no energy for its operation and will not start an ordinary watt-hour meter either when it is idle or when it is furnishing ringing current for an electric bell such as is usually installed in residences.

290. **There are two systems of electric gas lighting: The multiple and the series.** Series systems may be further subdivided into those operating from induction coils and those operating from frictional or static electric machines. The multiple system is the most common. The series system, which is best adapted for large auditoriums where many lights are used in groups, is seldom now used because such places are almost invariably lighted by electricity.

291. **The operation of the multiple system** is evident from Fig. 221. One battery terminal is grounded, or preferably, connects to a common battery wire. The other battery terminal connects through the spark coil to the terminals on the burners. If a common battery wire is used each burner must be insulated from the gas fixture with a rubber nipple. To light the gas, it is either first turned on or is turned on automatically by the burner mechanism and then further movement of the burner mechanism draws a wire wiper, which connects to one side of the battery, across an insulated wire hook which is mounted on the burner tip and which connects to the other side of the circuit. When the wiper leaves the hook a spark is drawn which lights the gas.

292. **Burners of different forms** are shown in Fig. 221. With the stem burner, the gas is lighted by turning the stem which turns on the gas and also draws the spark. With the simple pull burner the gas must be turned on by hand and then pulling the pendant draws the spark and lights the gas. With the rachet burner, one pull of the pendant turns on the gas and lights it and when the pendant is released the wiper and ratchet-pawl are returned to their normal position by a spiral spring. A second pull of the pendant turns off the gas. Automatic burners are so arranged that with them the gas can be lighted or turned off by pressing a button at any one of one or more control stations which can be located at any reasonable distance from the burner. Two insulated wires are required with each automatic burner where the gas pipe is used as a return and three wires are necessary where a non-grounded return is used.

293. **Spark coils** are necessary in electric gas lighting systems to insure that the spark at the burner will be "fat" enough that it will light the gas. The "fat" spark is produced by reason of the self-induction of the coil which acts to momentarily increase the voltage of a circuit enormously, through the coil when the circuit is broken. A spark coil for gas lighting usually consists of about 6 layers of No. 14 or No. 16, double-braid cotton-covered wire wound on a core $\frac{3}{4}$ in. in diameter consisting of a bundle of soft iron wire. The coils are made in various lengths of from 8 in. to 12 in. An 8 in. or a 10 in. coil of No. 16 wire is about right for the average gas lighting installation. A spark coil can be either pur-

chased with or equipped with a relay attachment (Fig. 222). The relay closes a bell circuit when there is a short-circuit on the system and the bell rings and gives an alarm. The bell can be operated from the gas lighting battery as indicated by the dotted lines but it is better practice to use a separate battery, as shown in the full

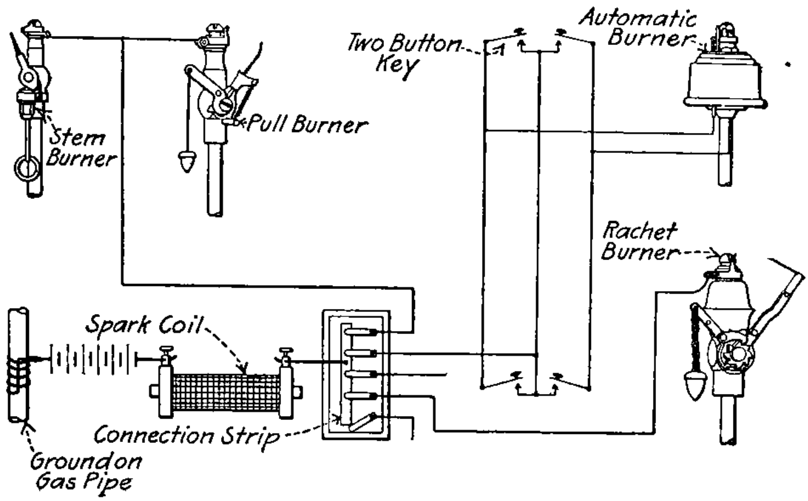


FIG. 221.—Multiple system of gas lighting.

lines, as the cells of the main battery used for such a purpose are liable to be exhausted much more rapidly than the others.

294. A connection strip (Figs. 221 and 222) whereby the leading wires running to the different burners or groups of burners can be disconnected from the battery for testing or in case of trouble should be provided in all gas lighting systems of any consequence.

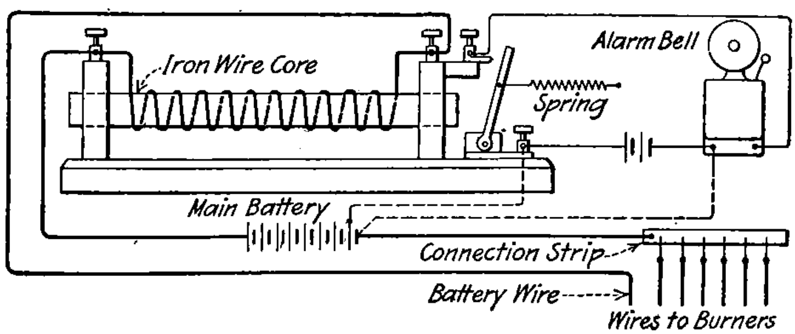


FIG. 222.—Spark coil with relay.

Such a strip may consist of a group of single-point switches or a strip of metal connected to the battery on which the ends of small metal straps normally bear. Each strap is pivoted at its outer end so it can be swung out of connection with the strip and the leading wires to the burners are connected to the pivoted ends.

295. **Batteries for gas lighting** should be of the open-circuit type and should have low internal resistance. Only cells of the very best grade should be used. A battery of 6 sal-ammoniac cells in combination with a spark coil will make a good spark.

296. **Wire for gas lighting systems,** from the battery to the fixture and for general wiring may be No. 16 weather-proof. On fixtures special wire, either No. 22 or 24, is used. These wires can be obtained with three windings of cotton, three windings of cotton and one of silk or with three windings of cotton soaked in a fire-proof compound and then served with an outer layer of silk. On fixtures the wire where possible may be carried within the tubing which covers the gas pipe stem. Care must be exercised that corners and edges do not cut the insulation. On fixture arms the wire is carried on the outside, held thereto with thread and then shellaced which holds it nicely. A helix or "pig-tail" should be formed in the wire at each joint in a bracket. Wire having an outer insulation of a color that matches the fixture should be used.

297. **In installing a multiple system of gas lighting** it is better to use a complete metallic circuit insulating the burners from the fixtures, but in small installations a ground (gas-pipe) return is satisfactory. Divide the burners into groups each served by one leading wire as illustrated in Fig. 221. There should not be more than 6 pull, stem or ratchet burners in any one group and each automatic burner should have its own leading wire direct from the battery. The National Electrical Code rules for installing gas lighting systems are the same as for other signal circuits operating at pressures of less than 10 volts. Electric gas lighting equipment cannot be installed on fixtures having both gas and electric lights.

298. **An automatic cut-out** should be installed in gas lighting systems of any consequence to protect the battery from grounds or short-circuits. In the cut-out the battery wire is connected to the coil of a relay which, when energized, permits a clockwork to operate. If the clockwork operates long enough it, through a mechanism, opens all of the circuits, leading to the burners, which terminate on the cut-out base or a connection strip. The relay is not energized for a sufficient length of time when a burner is operated to permit any great movement of the clockwork. However when a ground or short-circuit occurs on a circuit the clockwork soon opens the circuits. The clock movement must be wound occasionally.

299. **In the series system of gas lighting** (Fig. 223) a spark gap (Fig. 224) is installed at each burner. The spark gaps are connected in series by fine, bare copper wires (No. 26 gage) stretched between them. An induction coil, or sometimes a frictional electric machine, is used to produce the sparks or small arcs at the gaps. About 15 gaps may be allowed for every inch of spark or arc that the induction coil is capable of producing. The gaps are arranged in groups and each group is connected on a separate circuit after a method similar to that illustrated for multiple gas lighting. The gas is turned on and then the induction coil, it being in operation, is connected successively to the different groups, creates arcs at the gaps and lights the gas. Burners can often be arranged close

together so that one will light from another in which case a spark gap is required on only one burner of a group so arranged. The bare wires connecting burners should not be carried closer than $1\frac{1}{4}$ in. to metal work. Where this separation is impossible the wire should be encased in glass tubing. The voltage is very high and

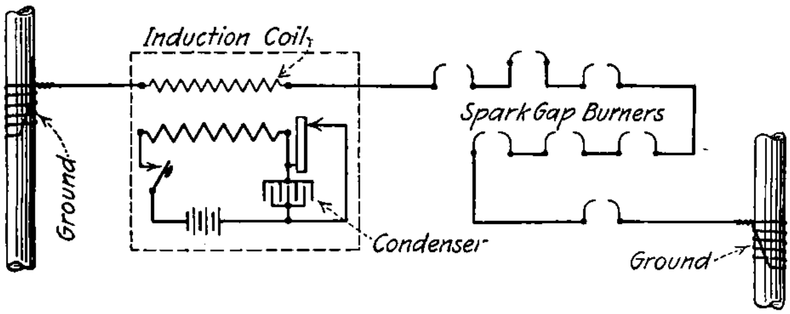


FIG. 223.—Diagram of series gas lighting system.

thorough insulation is essential. The condenser in the induction coil is for minimizing the spark at the vibrator.

300. **Burglar alarm systems** (*Standard Handbook*) are simply modifications of call bell systems; the bell circuit being closed whenever a door, window, transom or skylight, etc., is opened. More elaborate alarm systems entail the use of an annunciator indicating which window or door, etc., has been opened; a continuously ringing bell; a silent test switch to show that every window, door, etc., in the house has been properly closed; switch for testing bell and battery; a general switch for cutting out the alarm system during the day or whenever it is not required; lock switches for admitting persons with proper keys without sounding the alarm; attachments for lighting an incandescent lamp or gas-jet automatically when the alarm sounds so that the annunciator drop may be visible, and numerous other refinements.

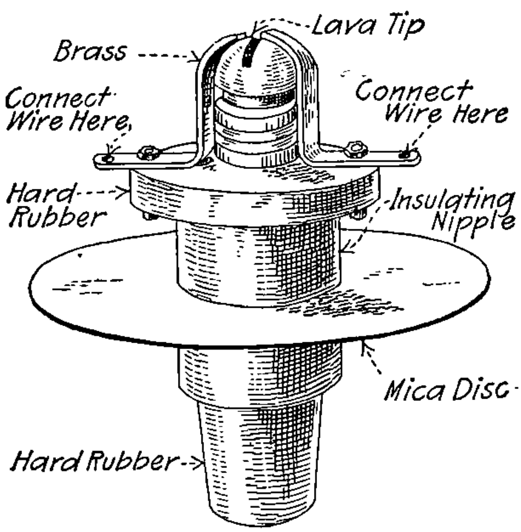


FIG. 224.—Spark gap burner for series gas lighting.

The chief requisite of an alarm system is the certainty of action of the apparatus and contacts. Since the apparatus may stand months and even years without being called into action, rubbing contacts, German silver springs, etc., are largely employed. Wires,

contacts, etc., should be concealed and should be installed in a first class manner.

301. **There are two classes of burglar alarm systems: open circuit and closed circuit.** In open-circuit systems the circuit or circuits to doors and windows throughout the building are normally open and when the circuits are closed by a door or window being

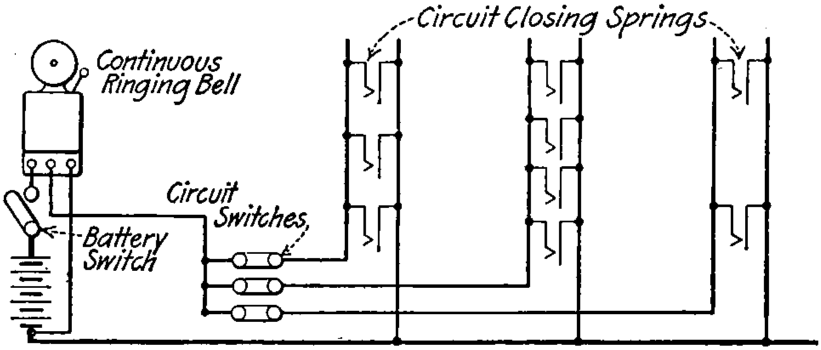


FIG. 225.—Simple open-circuit burglar-alarm system.

opened the alarm is sounded. In closed-circuit systems the circuit throughout the building is normally closed and current is flowing in it. When it is opened the alarm is sounded.

302. **Open-circuit systems** are shown in Figs. 225, 226 and 227. Some arrangement—a continuous ringing bell or drop—must be provided whereby the circuit through the alarm bell will remain continuously closed if a house circuit is closed instantaneously.

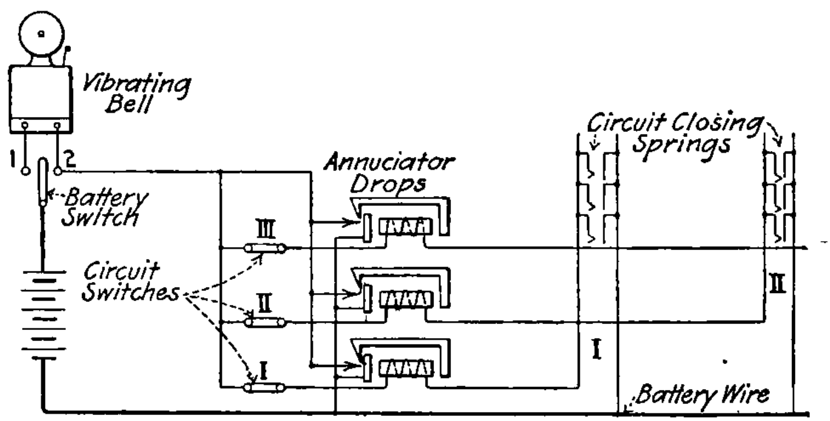


FIG. 226.—Open-circuit burglar-alarm system with alarm annunciator.

In setting the system for the night, the battery switch and the circuit switches are all opened. Then the battery switch is closed and the circuit switches are closed one at a time thereby locating any circuit on which there is trouble or on which a window may have been left open. Open-circuit systems are usually installed in preference to closed-circuit because of their simplicity.

303. **One objection to the open-circuit system** is that if the wires should be cut no protection is afforded, the alarm being then inoperative. When properly installed, however, the cutting of wires is a very rare occurrence. To guard against this possibility, a closed-circuit system may be installed in connection with the open-circuit system, the window, door and other contacts being arranged to open the circuit of a relay which thereby makes contact with the bell circuit. This system will give the alarm when the wires are cut, or when the closed-circuit battery is run down, or when a window, door, etc., has been opened. A straight closed-circuit system may also be installed.

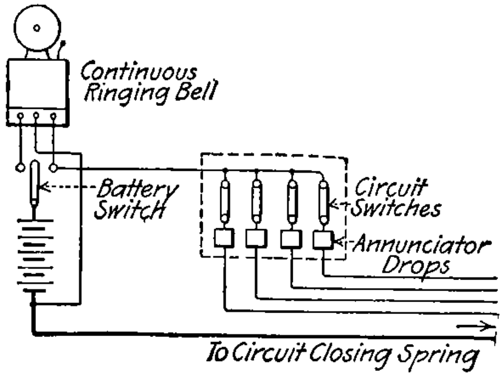


FIG. 227.—Open-circuit burglar-alarm system using an annunciator in combination with a continuous-ringing bell.

304. **Closed - circuit systems** are more sensitive than open circuit but are more liable to disarrangement. Fig. 228 shows an installation with two house circuits but usually one house circuit suffices. Fine bare copper wire (No. 24 gage) can be used for the house circuits and may be strung in front of doors, windows and objects to be protected so that its breakage will open the circuit and set off the alarm. Gravity cells are used for the closed-circuit battery and Le Clanche cells for the open-circuit battery.

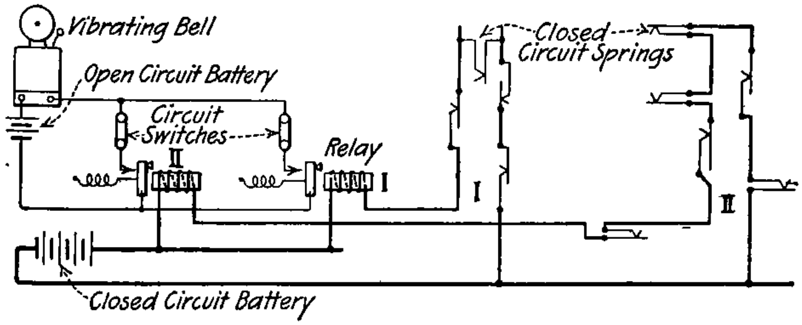


FIG. 228.—Closed circuit burglar alarm with two alarm circuits.

305. **Burglar alarm fittings** are shown in Fig. 229. Fig. V shows burglar alarm attachments for protecting windows, skylights, blinds, etc. A wire or string is attached to the ring and is drawn so as to break the contact. Further tension on the wire or string or its severance will establish the contact and give the alarm. Alarm springs for shades are shown in Fig. VI. The string of the shade is attached to the arm or hook so as to break the contact. Any interference with the setting makes contact and gives warning

of intruders. A lock burglar alarm switch is shown in Fig. VIII. This is placed on the door frame so that persons with proper keys can enter without giving the alarm. Turning the key opens the bell circuit.

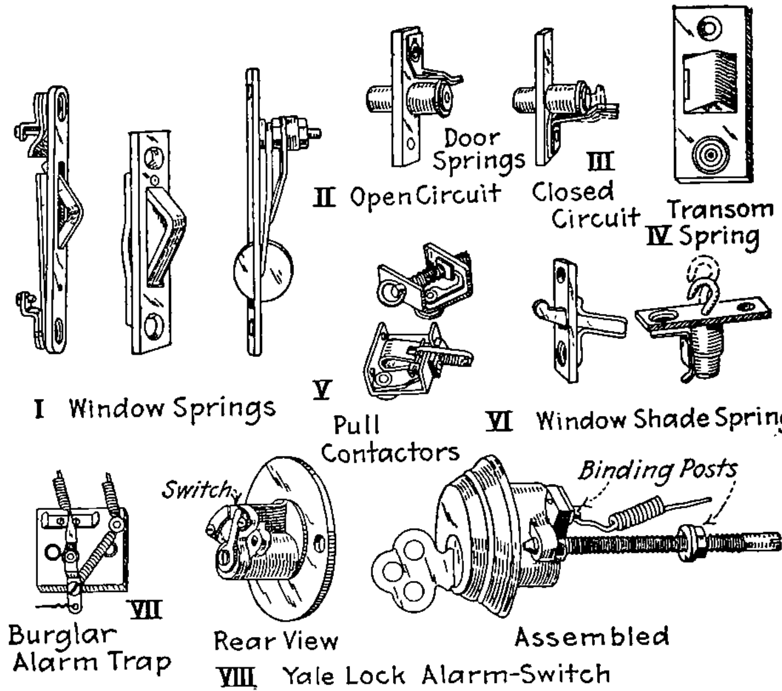


FIG. 229.—Burglar-alarm fittings.

A burglar alarm trap is shown in Fig. VII. This simple device has a great many applications. The illustration shows the trap in a balanced position, that is, the switch is not making contact. The string connected to the switch may be attached to a window, door, skylight, stretched across a hall, open doorway, etc., to be protected against intruders. The slightest disturbance of the string will draw the switch to one side and make contact and if the string is broken the spring will draw the switch to the opposite side and make contact so that in either case an alarm is given. An auto-drop or constant-ringing attachment is shown in Fig. 230. The bell circuit is closed automatically and is kept closed as long as desired. The drop is placed in the bell circuit and when the circuit is closed by a push button, door or window spring, the circuit-closer drop is operated by an electromagnet and keeps the circuit closed until the drop is raised again.

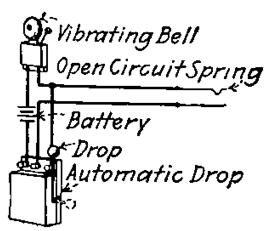


FIG. 230.—Constant ringing attachment.

Instead of contacts in windows, doors, etc., electric mats are sometimes used. An invisible electric mat is placed under the

carpet or other floor covering and which when trod on or touched by the foot sounds an alarm or signal in any part of the house by closing the bell circuit By this means windows may be left open for ventilation and protection still obtained.

306. Clock burglar alarms (*Standard Handbook*) (Fig. 231) may be had which automatically disconnect sections at predetermined times. These may also be fitted with a constant ringing switch, a servants' call switch, an incandescent lamp or an attachment for automatically lighting the whole house in case of an alarm. Switches are provided for testing each circuit leaving the annunciator; for testing the bell and line, and for testing the battery.

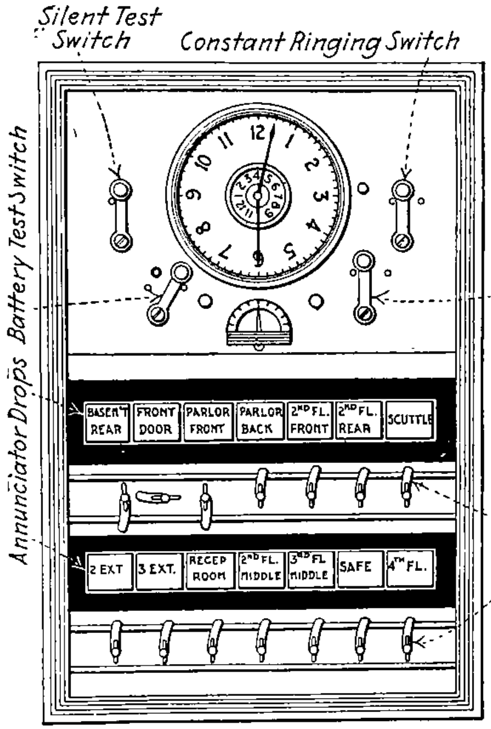


FIG. 231.—Burglar-alarm clock annunciator.

307. The installation of a burglar alarm system (open circuit) is shown in Fig. 232. It is to be understood that all the windows in one room are connected in multiple so that only one drop on the annunciator is required for each room. Fig. 233 shows the arrangement of a simple, closed-circuit, burglar-alarm system. All the contacts are arranged to open the closed-circuit when disturbed; this releases the armature of the relay which is instantly drawn by the spring to complete the bell circuit and give the alarm. This arrangement requires the use of both closed-circuit and open-circuit batteries, and while a trifle the more expensive is the most reliable system that can be installed. In

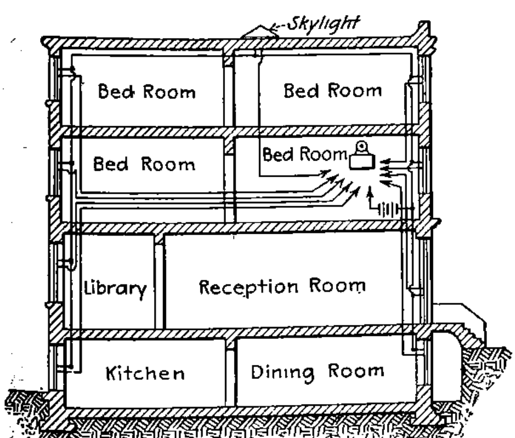


FIG. 232.—Open-circuit burglar-alarm system.

this system the alarm is given, the room indicated and the lamps throughout the building turned on whenever the circuit is opened. In closed-circuit systems a resistance should be placed in the circuit when the alarm is not set. (*Standard Handbook.*)

Circuit opening or closing springs are usually placed in window frames and door jambs. In installing springs be careful that the door or window fits snugly enough that the spring will lie in its normal position when the door or window is closed.

308. There are two general plans for installing interior telephone systems (*American Telephone Practice*). One is to install a switchboard at some central point to which all lines radiate and at which they are connected as desired by an operator. The switchboards and instruments are of the types made for small exchanges.

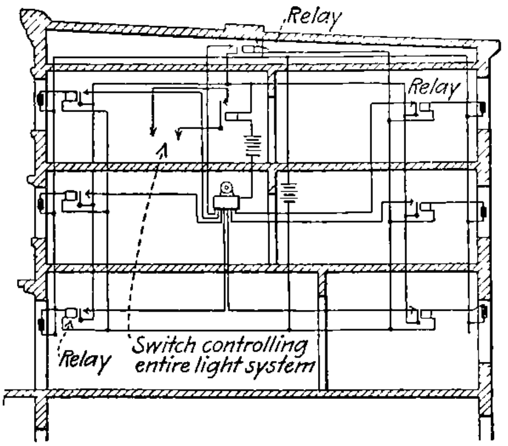


FIG. 233.—Closed-circuit burglar-alarm system. Annunciator indicator room and switch throws on all lights.

The second plan involves the use of an intercommunicating or house system in which the instrument at each station is placed on a separate line, the line belonging to each station passing through all of the other stations. By means of a switching device arranged at each station, the party at any station may, at will, connect his telephone with the line belonging to any other station and call the party at that station without the intervention of an operator. This plan involves the necessity of running at least one more wire than there are instruments in the exchange through each one of the stations and the simplest way to do this is to run a cable having the requisite number of conductors through each of the stations, all of the conductors in the cable being tapped off to the switch contact points on each telephone.

From 12 to 20 stations is considered a maximum for intercommunicating systems. Where there are more stations a switchboard should be installed.

309. Local battery telephones may be divided into two classes, series and bridging. The series instruments are adapted for use on single station lines in exchange work or on a line connecting only two instruments. This type is termed series because the generator and bell are connected in series with each other and further because it was formerly the practice on party lines to connect such instruments in series in the line. The bridging instruments are so called because the generator and ringer are separately bridged across the line and in party line work it is common to connect such instruments in multiple on the line.

310. **The circuit of a series instrument** is shown in Fig. 234, *I*. The switch hook is shown in its raised position so as to connect the receiver and the secondary of the induction coil in series in a circuit between the binding posts of the instrument. At the same time the transmitter, the primary of the induction coil and the battery are connected in a local circuit by themselves. This is the condition

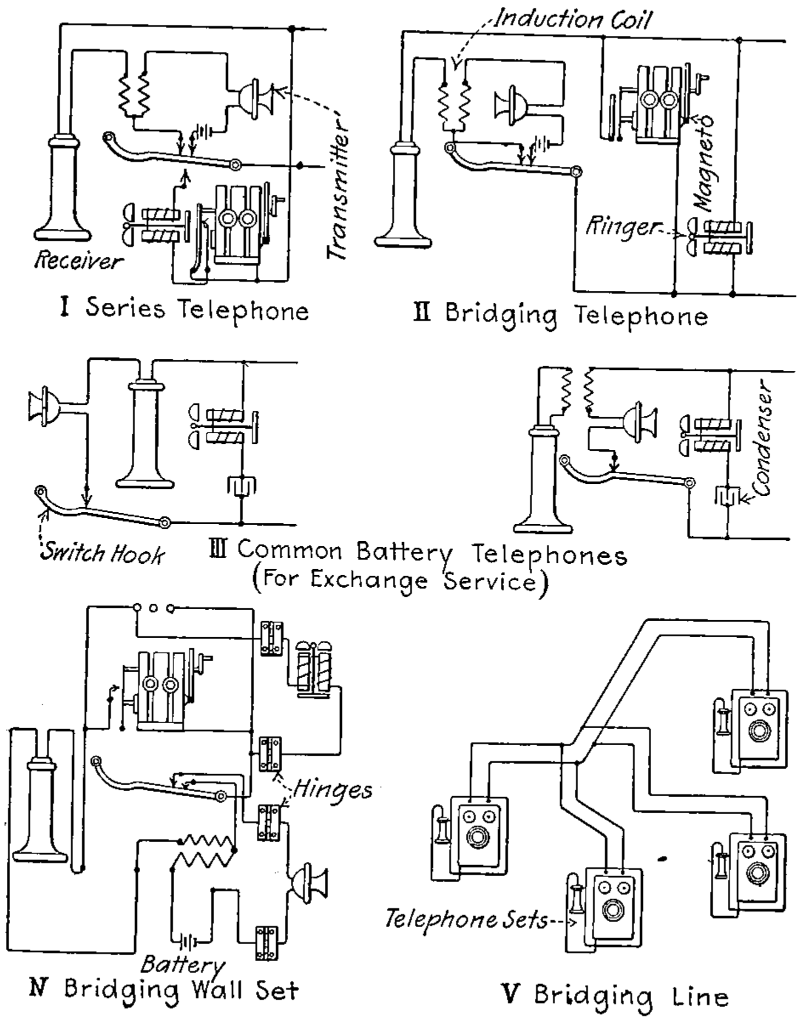


FIG. 234.—Telephone circuits.

for receiving or transmitting speech. When the hook is depressed, as when the telephone is not in use, the bell or ringer is connected across the terminal posts. This circuit would also include the generator but for the fact that it is normally shunted out by springs. The contact between these springs is automatically opened, however, when the generator is operated and then there is current from the generator to the line through the bell. The springs form what

is called an "automatic shunt" for the generator, their function being to cut out the resistance of the generator armature from the circuit at all times except when the generator is in use.

311. **The circuit of the bridging telephone** is shown in Fig. 234, *II*. In this, the arrangement of the receiver, induction coil, transmitter and battery are identical with that in the series telephone. The ringer, however, is bridged permanently across the line and the generator is placed in a circuit across the line which is normally open but which is closed automatically by a spring when the generator is operated. The magnets of the ringer or bell are wound with many turns of fine wire. This gives them great impedance. The talking currents, which are high-frequency alternating currents, do not, therefore, pass through the ringer coils. The ringing currents can readily pass through the ringer coils and cause them to operate.

312. **The circuits of an assembled bridging telephone** are shown in Fig. 234, *IV*. As the ringer and the transmitter are mounted on the door of the instrument box the connection between them and the other parts of the apparatus is made through the hinges as shown. Note that the circuits are identical with those given for the elementary bridging instrument.

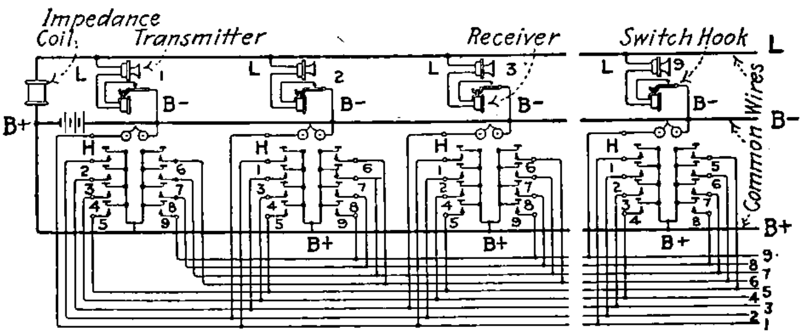


FIG. 235.—Selective-ringing, common-talking, private-line system.

313. **A simple intercommunicating system which permits of but two parties talking simultaneously** is shown in Fig. 235. As furnished by the Western Electric Company, the bells are wound to 10 ohms resistance insuring minimum draught of current from the battery and long battery life. The transmitter and receiver are of high resistance and the impedance of a coil through which battery is supplied to the transmission circuit prevents the shunting of talking currents through the battery. The use of high-resistance transmitters and receivers insures that the most distant instrument will receive practically as much as those near the batteries. The wall instruments are quite similar in external arrangement to that of Fig. 242, but are furnished in the surface type only. Desk instruments can also be supplied.

314. **The circuits of an ordinary lever switch intercommunicating system** are shown in Fig. 236. One station calls another by the turning of a magneto generator, the switch lever having first been moved into contact with the button corresponding to the

number of the station desired. The disadvantage of the system is that the switch lever must always be returned to the "home" button or endless confusion from cross signals will result.

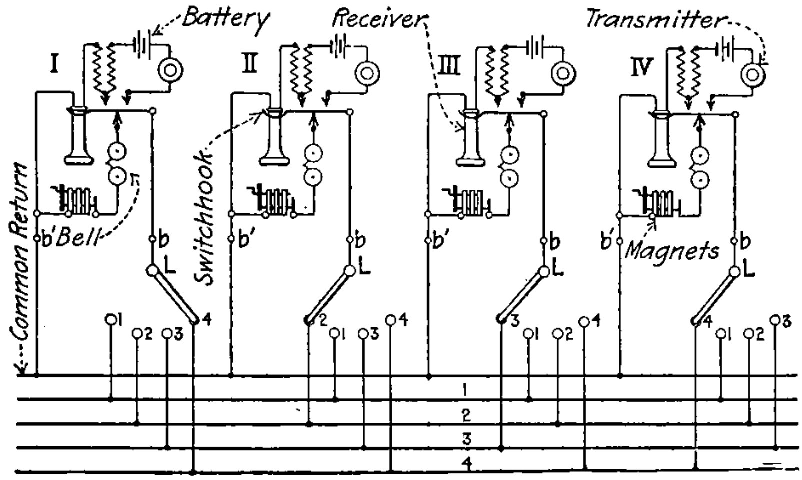


FIG. 236.—Circuit of lever switch intercommunicating system.

315. The circuits of a common-battery, common-return plug and jack intercommunicating system are shown in Fig. 237. The wiring for 10 stations is shown but only 5 of them are indicated. The plug is inserted in the jack corresponding to the station wanted

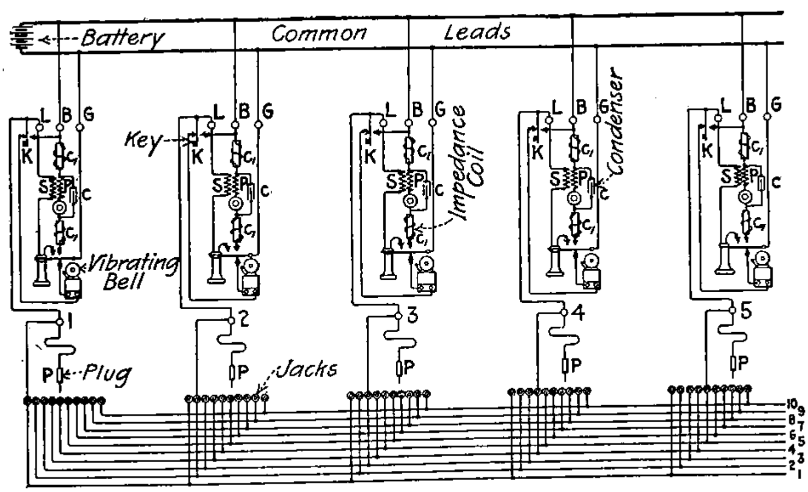


FIG. 237.—Common-battery, common-return, plug and jack, intercommunicating system.

and a pressure of the key rings the wanted station's bell. Impedance coils are inserted in the primary circuits to reduce cross talk and the transmitter is bridged by a condenser which provides a local circuit for the talking currents set up by the transmitter.

The plug must be removed after a conversation, or cross ringing will result.

316. **The circuits of the Holtzer-Cabot intercommunicating system** are shown in Fig. 238. The switch is so arranged with a ratchet wheel that it will be released and fly back to normal position through the action of a spring when, after a conversation is finished, the receiver is hung up. The switch lever at each station is arranged to slide over and make contact with the buttons. However, the curved contact piece is so arranged that the lever will not normally

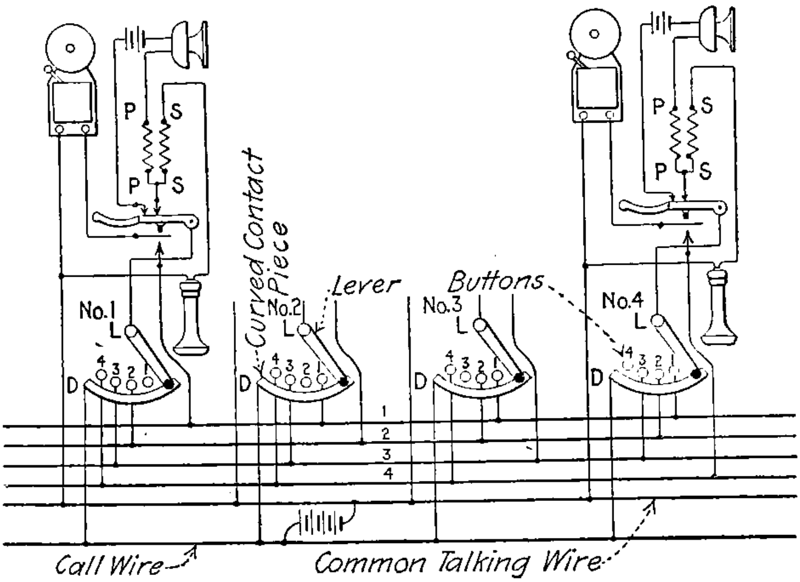


FIG. 238.—"Holtzer-Cabot" system circuits.

engage it but by pressing on the handle of the lever it may be brought into engagement and thereby complete the ringing circuits through the bells of both stations.

317. **The circuits of a metallic circuit intercommunicating system using plugs and jacks or keys instead of a switch** are shown in Fig. 239. In many systems the fault exists that if a person at one station fails to return his switch to normal after using his telephone, he cannot be called by others because his instrument is not connected with his own line. In the circuit shown this is avoided by permanently connecting the bell belonging to each station across the line of that station.

There are five lines running through five separate stations and the call-receiving bell *B* on each line is permanently bridged across the line at that station bearing the same number as the line. Two-point spring jacks are provided at each station for each line and the subscriber's telephone set and generator may be switched into the circuit of any line by inserting the plug in the proper jack. Thus if a party at Station No. 1 desires to call Station No. 5, the plug at station No. 1 would be inserted in jack No. 5 and the generator operated. This would ring the bell at Station No. 5 and the party

at that station would respond by inserting the plug in his own home jack. When through talking, if the party at Station No. 1 left his plug in connection with line No. 5, no harm would be done

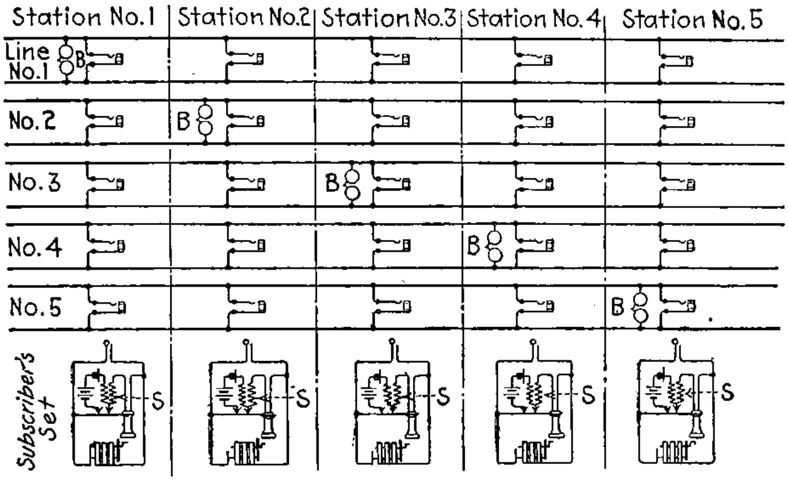


FIG. 239.—A plug-in intercommunicating system.

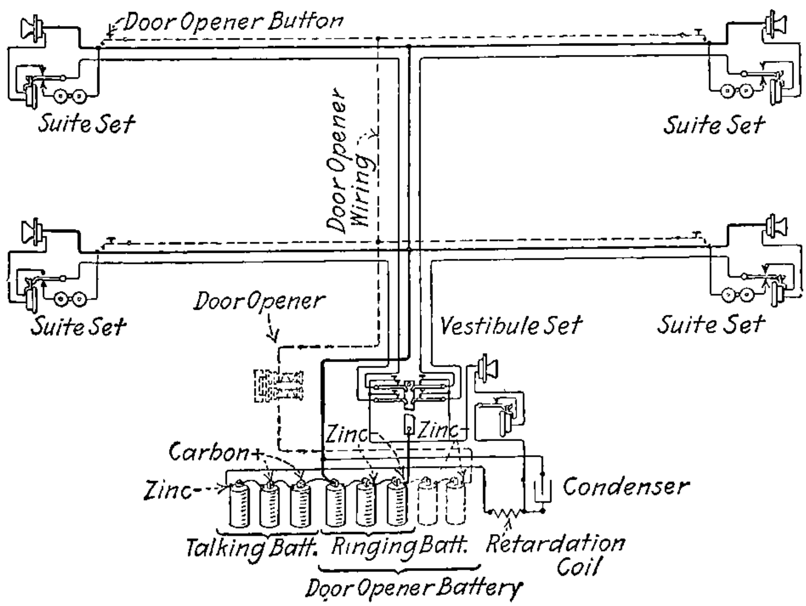


FIG. 240.—Apartment house system giving service between vestibule and apartments.

as other parties could operate the call bells of either line, No. 1 or No. 5, just as well with the plug inserted as with it out.

Instead of using plugs and jacks, as shown in Fig. 239, to effect the connection of the telephones with the various lines, a more

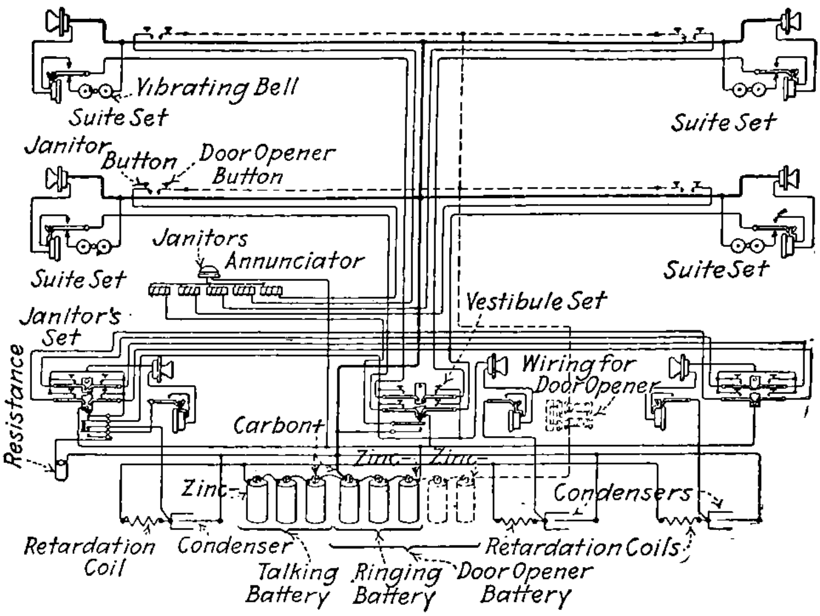


FIG. 241.—System giving service between vestibule and apartments, vestibule and janitor and tradesmen and apartments.

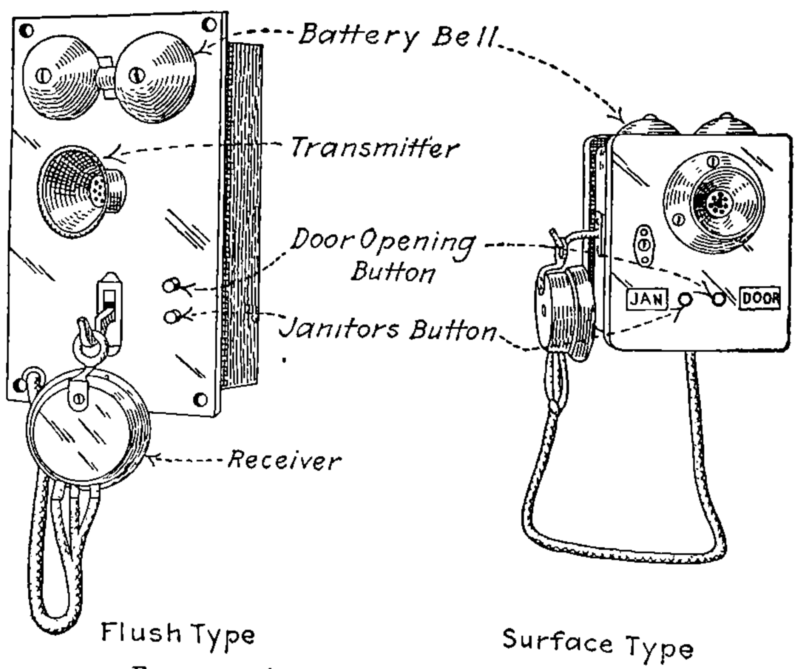


FIG. 242.—Apartment-house suite telephones.

convenient arrangement, described hereinafter, involving, however, the same principle, is to employ push buttons or keys. The proper connection with these is made by pushing a key instead of inserting a plug in a jack.

318. **Apartment house telephone system circuits** are shown in Figs. 240 and 241 which are recommended when the installation of a

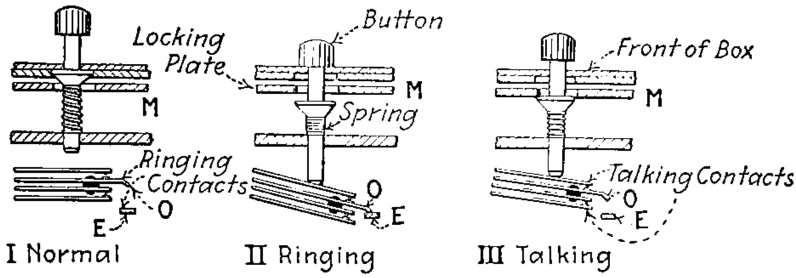


FIG. 243.—Positions of intercommunicating key.

private branch exchange is not justified. These illustrations show Western Electric Company's Interphone systems. The suite telephones (Fig. 242) may be of either the flush or surface types. The talking battery is fed through retardation coils, so in installation where there is provision for simultaneous conversation between two stations, there cannot be cross talk. The receiver and transmitter in the telephones are in series, an induction coil not being

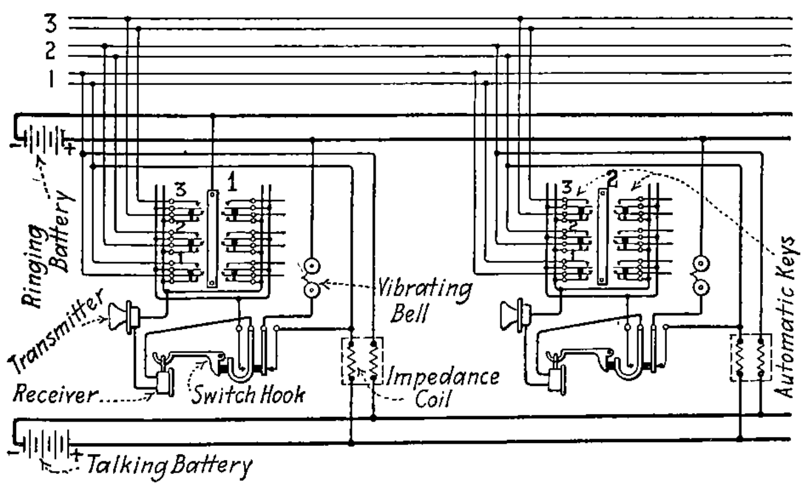


FIG. 244.—Automatic-key intercommunicating sets. Any two or more stations on the system can converse simultaneously.

necessary for the short distances involved. The calling buttons on the telephones make connections as described in paragraph 319. Where a janitor's set is installed, the annunciator for it is similar to ordinary annunciators. One janitor's equipment can be made to serve any reasonable number of vestibules and apartments by making proper modifications. The bells in the apartments are wound to 10 ohms and the resistance of the janitor's annunciator

drop plus that of his bell is 10 ohms, which insures minimum draught of current from the battery and maximum battery life. Ordinary electric bells have about 2 or 3 ohms resistance.

319. The operation of the keys in an interphone instrument is shown in Fig. 243. When the button is pressed all the way down as at *II*, the ringing position of the key, contact is made with the line wires of the station called and ringing current is thrown out on that line. When the pressure on the button is released, it assumes an intermediate position, *III*, the talking position, and the ringing contacts *o* and *e* are open but contact with the line for talking purposes is maintained. The key is automatically held in this intermediate position by a locking plate *m* until this plate is actuated by the operation of any other button in the telephone which releases the key so that it assumes its normal position as shown at *I*.

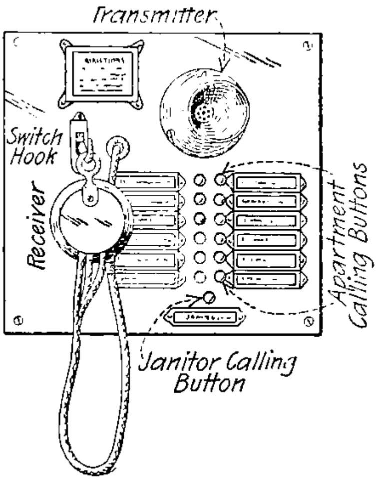


FIG. 245.—Flush-type vestibule, janitor's or tradesman's set.

320. An automatic key intercommunicating system which permits simultaneous communication between stations is shown in Fig. 244. This is a Western Electric Company Interphone circuit, but similar arrangements are furnished by other concerns. The instruments are quite similar in appearance to that of Fig. 245 and may be of either the flush or surface type, or desk sets can be used. The operation of the automatic keys is described in para-

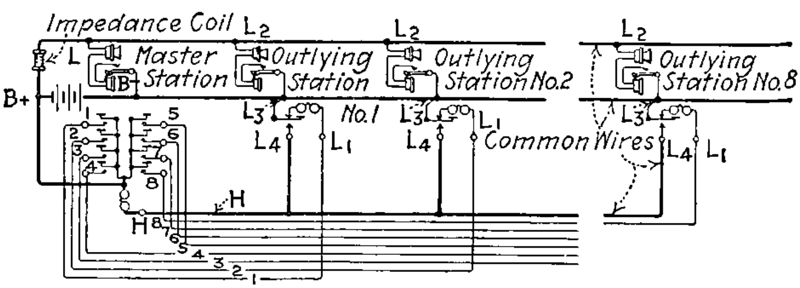


FIG. 246.—Selective-ringing, common-talking system Outlying stations cannot intercommunicate.

graph 319. Wiring between stations may be full metallic as shown or common return. Full metallic is recommended and instruments are arranged for it, but can be easily altered by the wireman for common return. Circuit arrangements can be provided insuring secret service between certain stations. Three or more parties can converse with each other at once by depressing the proper calling buttons.

321. **An arrangement wherein the master station can call any outlying station but the outlying station can call only the master station** is shown in Fig. 246 which gives the Western Electric circuit. In general this is similar to the scheme of Fig. 235. The arrangement is used in schools, factories, stores, banks and offices where an executive communicates with subordinates and they with him, but where there is no occasion for the subordinates communicating with each other.

322. **Conductors for telephone wiring** (*Standard Handbook*) are usually of rubber-covered, twisted pair, copper wire, but the work may often be done much better and cheaper, particularly in large buildings, with lead-covered paper-insulated cable such as is used by telephone companies in the subways. These cables are smaller for the same number of wires and are less costly than cables containing the same number of wires rubber-insulated. Paper cables less than 3 in. in diameter and containing as many as 600 pairs can be obtained. Of course with this type of cable all the terminals of the cable or its branches must be made with lead-covered, silk-and-cotton insulated cables, as the paper insulation will not stand handling when exposed. Where the terminal is in a damp location the run should be made with rubber-covered wire. Shafts are preferable to iron conduit for carrying the main riser cables, as it is a difficult matter to make splices between the riser cables and the floor terminal cables if the former are run in conduit.

323. **In installing telephone cables** or conductors for a system a few spare pairs should always be included. Where this is done the installation of additional stations is inexpensive. Instruments having provision for more stations than required for the initial installation should be used to obviate the replacement of the instruments which is otherwise necessary when additional stations are put in.

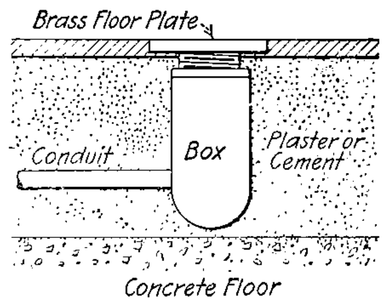


FIG. 247.—Signal-circuit, floor-outlet, box.

324. **In wiring for telephones and signaling systems in department stores** (*Standard Handbook*) or in other places where it is desirable to have outlets for counters or on desks, a very flexible system may be installed as follows: Lines of ½-in. galvanized pipe may be laid under the floor from the riser shafts and arranged to checker the floor (Fig. 248) in such a manner that all parts of the floor are within short range of the outlet points. Connection boxes (Fig. 247) may be installed at intervals of 50 ft. into which the lines of conduit are bushed. These boxes should be large enough and square and should be fitted with tight-fitting brass cover-plates flush with the surface of the finished floor. Service outlets through which connections may be extended to telephones, bells, etc., may be located approximately 10 ft. apart throughout the entire system.

From these outlet-tees and the vacant sides of the connection

boxes, wires may be fished under the floor to any desired point. The tees in the conduit may be entirely concealed beneath the floor and made accessible through removable sections of the flooring above them. The tees may be normally plugged, and may be fitted with outlet bushings when connections are to be made through them.

The connections for these low voltage circuits may be made through 2-in. conduit risers located in the same space as the lighting risers. Special interconnected panels (Fig. 249) should be provided at every floor through which branch connections to the underfloor conduit system may be easily made. The interchanging of connections may also be made at these panels. This system may be used for all telephone, bell and signal wires.

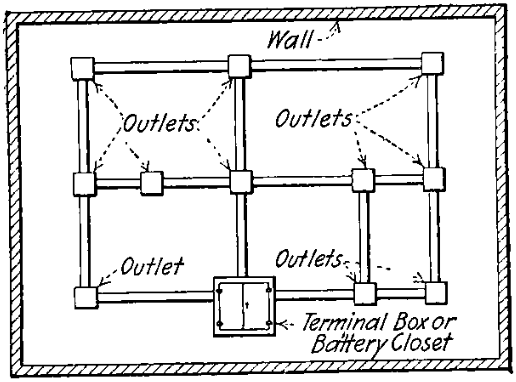


FIG. 248.—Conduit system for signalling installation.

325. **For wiring large office buildings for telephones** (*Standard Handbook*) a very economical and satisfactory system can be arranged as follows: One or more terminal boxes are provided on each floor at points adjacent to vertical pipe-shafts. Elevator shafts can frequently be used for this purpose. From the basement one or more cables are extended up through these shafts. Branch taps of sufficient size to provide for service on each floor are terminated in the terminal boxes. The riser cables and the service cables from the telephone exchange should terminate in a common main terminal in the basement so that connections can be easily made between the two sets of cables. The terminal boxes should be placed near the ceiling and wide shell molding should be provided in the halls for carrying the wires from the terminal boxes to the rooms. A smaller molding should also be provided for carrying the wires in the individual rooms.

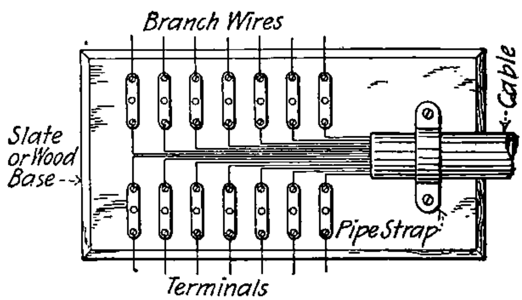


FIG. 249.—Interconnection board.

Where the wires enter the room from the hall, a piece of $\frac{3}{4}$-in. conduit should be furnished for carrying the wires through the partition. This conduit should be either lined with insulating material or the sharp edges around the inside of the pipe should be rounded off. Where it is necessary to run across the ceiling of a hall in order

to avoid either carrying the exposed wires across the finished ceiling, or making a circuitous run around the hall to reach the rooms on the opposite side from the floor terminal, conduit should be installed across the ceiling before the plastering is completed for the purpose of carrying a small branch cable to provide for such lines.

326. **When wiring large hotels and apartment houses for telephones** (*Standard Handbook*) it may be taken for granted that one telephone will be required in each room of a hotel and one for each apartment in an apartment house. In office buildings, a number of telephones may be required in one room, and a very flexible system of wiring must be installed. In hotels the wiring involves the running of a pair of wires from each room to a common center near the switchboard which is usually located on the first floor. Provision should also be made so that the cable of the telephone company carrying the trunk lines may run from the switchboard to the outside of the building. A 2-in. conduit is usually large enough for this purpose, but the local telephone company which usually installs the wires after the race ways are in place should be consulted.

From the telephone switchboard a cable is run through the vertical pipe shaft. The size of this cable diminishes as it extends up through the building. At each box a tap is terminated of sufficient size to provide wires for all telephones on that floor. From the terminal boxes on each floor twisted pairs of rubber-insulated wires are run through the conduits to locations in each room.

A very simple manner of wiring apartment or hotel buildings for telephones is to place a terminal box on each floor convenient to a vertical pipe shaft. From this terminal box a $\frac{1}{2}$-in. conduit is run to a designated location in the wall of each room. The height of the outlet should be 4 ft. 10 in. from the finished floor. This conduit should not be over 50 ft. long and should have not more than three bends with a minimum radius of five inches. Any conduit 100 ft. long should be not less than 1 in. in diameter; $\frac{1}{2}$-in. conduit should be provided for a maximum of two pairs of wires; $\frac{3}{4}$-in. conduit for five pairs, and 1-in. conduit for ten pairs. In extending the conduit from the terminal box to rooms, it is possible to use one run of larger conduit to supply a number of rooms, rather than run small conduit to each room. Where the floor area is large and the number of telephones required is great, it may be found economical to install more than one terminal box on a floor.

327. **In relatively small apartment houses** where only one telephone is required in each apartment, it is an easy matter to run a vertical conduit up through each tier of apartments and provide an outlet in each apartment. Individual pairs of twisted rubber covered wire can then be pulled from the switchboard through the conduit for each telephone. The individual wires can be carried in a cable from the bottom of the risers to the switchboard.

328. **The number of telephone wires to be provided** in a building depends, of course, on the building and the class of business for which it is to be used. A rough average is one pair per 200 sq. ft. of floor space in financial buildings, and one pair for every 300 sq. ft. of floor space in commercial buildings.

DESIGN OF INTERIOR WIRING INSTALLATION

329. **Factors Affecting Wiring Lay-outs** (*Standard Handbook*).—In conduit work the space available often dictates that the feeders be split up into two or more feeder lines. Conduit larger than 2 in. in diameter is not easily handled, and even if the run were such that 2-in. conduit could be easily installed, it would be preferable to install smaller conduit and divide the feeders so as to guard against complete shut down should anything happen to the feeders. Very often the mistake is made of installing feeders just large enough to carry the present load, and when additions are called for the feeders are overloaded and additional feeders must be installed at great expense. The same is true of branch circuits. The maximum allowance of 660 watts on branch circuits should not be used up. Frequently a larger lamp may be substituted for a 16-c.p. lamp; in fact, this is very easily done because of the fact that the lamp socket will take any size of incandescent lamp up to 500 c.p. and circuits are thus easily overloaded. It is usual to connect up about 400 watts so that fans, etc., may be connected afterward without overloading the circuit.

330. **In selecting a system for wiring for light** one should be used whereby 110 volts or thereabouts can be impressed on the lamp terminals. Nominal 110-volt incandescent lamps, including those of voltages of from say 90 volts to 125 volts, are more efficient, cheaper and have longer lives than those for higher voltages. Lamps of nominal voltages of about 50 volts are seldom used now and require excessive expenditures for copper conductors. The three-wire system is much more economical of copper than a two-wire system, therefore should be used for feeders and mains in installations of any consequence; then the two-wire system is used for branches. Three-phase systems can be used for lighting as elsewhere described (see index) and can be used to advantage in industrial plants where the use of constant speed motors makes the use of the three-phase system desirable.

331. **The method to use for wiring a building** is determined by conditions. *For residences:* Exposed work on knobs and cleats is cheap and safe but seldom used because of its unsightliness. Molding work is sometimes used in old buildings but does not look well. The knob and tube method can be used when the building is being wired while under construction or in wiring an old building. It is a low-cost method and quite safe. Either rigid or flexible conduit or steel armored conductor wiring are best and also most expensive. In many communities, conduit or steel armored conductor wiring are the only methods permitted for concealed work. Flexible steel armored conductors provide the best and safest installation for wiring old buildings. *For business and public buildings* of frame or of brick and frame construction the above suggestions for residence wiring apply. For fire-proof buildings the rigid, wrought-iron conduit method is used almost exclusively.

332. **In planning the wiring for a residence** secure the floor plans of the building or, if it is a small one, inspect the building. Decide first where the meter is to be located, as the point of entrance

to the building should be as close to the meter as possible. Some central station companies specify where meters shall be located. Often the meter can be located and the service wires enter in the cellar, as in Fig. 250. A kitchen is a poor location for meters because they will get greasy and collect dirt. Where the service wires enter between the first and second floors a good location for the meter is in a rear hall or in the pantry. Meters should not be located in attics or where the readers must climb stairs to reach them. A basement or a first floor entrance is the best.

The meter location having been determined, ascertain how many lamp outlets there will be, the current taken at each, and where

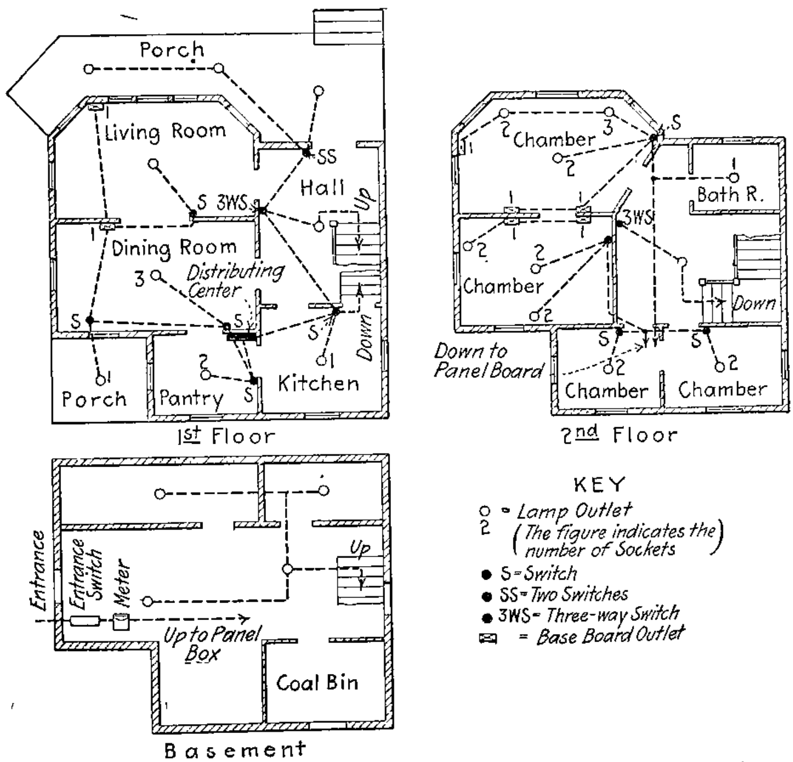


FIG. 250.—Wiring lay-out in a two-story house (Conduit Method).

the outlets will be located. Decide on the location of the distributing center as directed in another paragraph. Divide the outlets into groups requiring less than 660 watts, each group to be fed by a branch circuit from the distributing center. No branch circuit feeding incandescent lamps can have a load in excess of 660 watts connected to it and it is better to so subdivide the outlets that no branch circuit will have an initial load greater than about 440 watts which allows 220 watts for growth. Fig. 250 shows the subdivision of branch circuits radiating from a distributing center throughout a house. Locate the switches. Calculate the size of feeder that will be required in accordance with directions given

elsewhere herein. If load exceeds 660 watts it is best to use a three-wire service. Incandescent lamp branch circuits are usually of No. 14 wire unless they are over 100 ft. long when wire at least as large as No. 12 should be used. No. 14 is the smallest size permitted by the *Code*. Figs. 250 and 252 show plans for conduit jobs, with non-conduit jobs the arrangement would be the same except that splices could be made elsewhere than in outlet boxes.

333. **The wiring in a residence between the entrance and the distributing center** is shown with a three-wire feeder in Fig. 251. A fused entrance switch is always inserted in the feeder circuit immediately inside of the building, then comes the meter and finally the branch blocks or panel box whereby the branch circuits are tapped from the feeder for distribution throughout the building. With a two-wire feeder the arrangement would be similar.

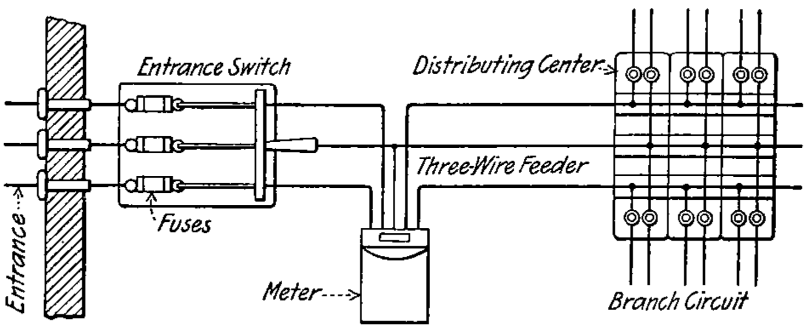


FIG. 251.—Wiring between entrance and distributing center.

334. **Distributing Centers in Residences.**—Often one panel or a group of cut-out blocks is sufficient for an entire house of three stories or less and not requiring more than 10 or 12 branch circuits. See other items in this section describing panel boxes and their construction. It is much better, if possible, to locate all cut-outs in one group than to distribute them all through a house. In a one-story house all branch cut-outs or panel boxes can usually be located near the meter at the entrance or in a hall. In a two-story house the best location is usually in the stairway to the cellar or in the rear hall. In a three-story house the best location for the distributing center is usually in the second floor hall. Where there are more than three stories, distributing centers can be effectively located on every third or second floor. Fig. 252 shows the wiring plan and distributing center in a one-story residence. Closets are considered very unsafe locations for distributing centers.

335. **Things to Consider when Laying Out Residence Wiring** (*National Electric Light Association Bulletin*).—*Three-way switches* should be used to control the hall lights on two or more floors from any floor. *A double-control switch* can be installed in any room whereby a portion or all of the lamps in the room can be lighted or extinguished with this same switch. *Wall switches* should be located so that the door which they are near will not cover them when they are open. *A master switch* for throwing on all of the lights in the

house in case of accident can be located in the owner's bed room. *A closet door switch* can be inserted in the jamb of a closet door whereby a lamp in the closet will be automatically lighted when the door is opened. Through the use of a chain pull socket for the closet lamp, waste of electricity can be avoided when the door is open. *Switches for front porch and lower hall lamps* should be located conveniently near the door so one can reach in from the outside, with the door partially open, and turn them on or can, when inside, open the door with one hand and turn the switch with

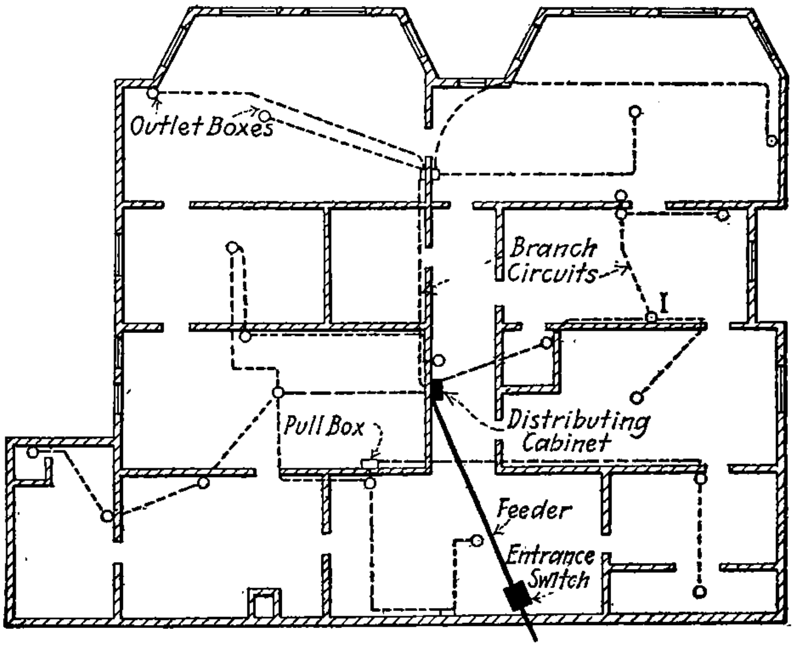


FIG. 252.—Conduit wiring in a one-story residence.

the other. *A cellar beacon light*, a small red lamp near the cellar lamp switch, can be arranged to remain lighted so long as the cellar lamps are burning. *Bathroom lamp outlets* should be so arranged that shadows will not be cast against windows.

336. There are five points that must be considered in designing the wiring lay-out for a large building (*Knox, Electric Light Wiring*) They are:

1. *Control of groups of receivers* (*other than hall or night lights*) *from the main switchboard.*
2. *Control of hall lights from the main switchboard.*
3. *Maximum load that should be served by one feeder.*
4. *The best maximum limit for the size of the feeder conductors.*
5. *The proportion of the total voltage drop that can be allowed in feeders and mains.*

Each of these items will be separately considered in the following paragraphs. By a receiver is meant any device that consumes electrical energy.

337. **Control of groups of receivers (other than hall or night lights) from the main switchboard.** Where it is desirable to control a group of receivers from the main switchboard in the basement, a separate feeder must be carried from it to each group to be so controlled. Usually the feeder system can be laid out without regard to the control of the room lights, because, as a rule, they do not have to be controlled from the switchboard. It is usually advisable to have each of the lower floors, up to and including the ground floor, on a separate switch as these floors often require light when the others do not. Special lighting appliances such as sign, clock dial and outside dome lights require separate feeders from the switchboard because they are turned on and off at set times from the switchboard. Certain motors may require similar control. In hotels the feeder switches are never opened except in case of accident so, from a control standpoint only, it is not necessary to subdivide hotel feeders. Where tenants of portions of buildings pay for the light they use it is often desirable to carry a separate feeder from the switchboard to each tenant's suite so that all meters can be located together at the switchboard. Suites can be metered separately by cutting meters in the mains at the suites but this may be undesirable.

338. **The control of hall lights from the main switchboard** is an important consideration. In private dwellings it does not usually pay to install a separate feeder for the hall lights, and it may not be necessary in a hotel where attendants are constantly passing in the halls. In a majority of public buildings, however, separate control of the hall lights is very desirable if not necessary. The usual problem is, then, whether there shall be one or two sets of hall light feeders. With two sets of feeders for hall lights local switches may be eliminated and control effected entirely from the main switchboard. Two sets of hall feeders increase the cost of installation but the saving in energy usually justifies them. By arranging two sets of feeders, one set serving say, one-third the hall lights and the other the remaining two-thirds, the smaller group can be used for dark days and for an all-night circuit and a saving in energy will result. Where there are two sets of hall lights thus controlled the wiring of outlets should be such that there will be a uniform distribution of light whichever set is lighted. Where tenants pay for the energy used in their suites a separate feeder for the hall lights is indispensable.

339. **Maximum Load that Should be Served by One Feeder.**—It is impossible to give a hard and fast rule covering this feature. The total load in the building, the available space for the switchboard, the method of control desired and the cost all influence a decision. The load should always be somewhat subdivided to localize trouble and so that, in an isolated plant, the engineer can disconnect portions of the load, while he is getting another machine on the line, when the load comes on suddenly.

340. **Best Maximum Limit for the Size of Feeder Conductors.**—On a basis of cost alone it is usually cheaper to run a few large conductors than a great number of small ones. It does not pay, however, to use conductors larger than 1,000,000 cir. mils. When

greater capacity is required it is cheaper to subdivide, so that several conductors will have the aggregate capacity required. For alternating currents, conductors larger than 700,000 cir. mils are not desirable because of skin effect. Often the space available for conductor runs makes it necessary to use small conductors. Each case must be decided on its merits.

341. The Proportion of the Total Voltage Drop that can be allowed in Feeders and Mains.—Distribution of drop is discussed in another section and it is there stated that it is usual to confine certain proportions of the drop to the feeders, certain proportions to the mains and certain proportions to the branches. As the allowable voltage drop determines the size of a feeder or main it is evident that the lay-out of feeders and mains for any given job will in a measure depend on the drop distribution. Where the load on an incandescent lighting feeder exceeds 660 to 1000 watts, a three-wire feeder should be used to insure good voltage regulation and maximum economy of copper.

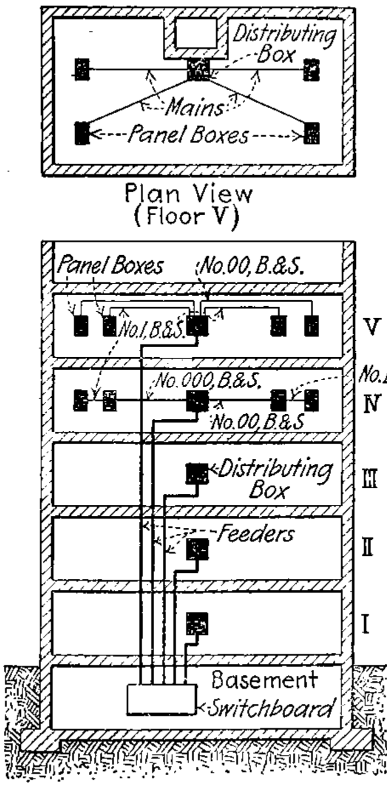


FIG. 253.—Individual feeder to each floor.

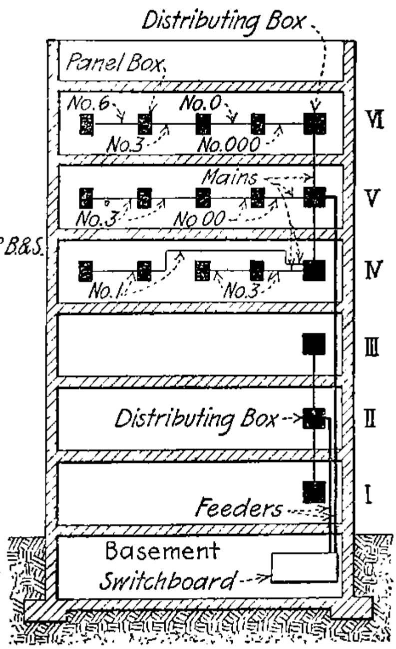


FIG. 254.—One feeder serving three floors.

342. To design the wiring lay-out for a large building make a sectional-elevation drawing of the structure and a plan drawing of each floor. Indicate the receivers (lamps and motors) on the plans and then locate panel boxes so that, in general, no lighting branch circuit will be much over 100 ft. long or have a load much greater than 400 watts. While 660 watts is allowable it is well

to provide the 220 watts spare capacity. Panel boxes should be placed so that they can be readily reached and so that the branch circuits, mains and feeders can be run to them. Compute the load on each panel box and indicate it on the drawing at the box.

Now lay out the mains and feeders. First decide whether the hall or public lights will be controlled separately, or together with the private lights from the main switchboard because this feature affects the arrangement of the feeders and possibly that of the mains. Next decide (note conditions outlined above affecting this matter) whether there should be a separate feeder to each floor as in Fig. 253, or whether several floors or portions thereof will be served by

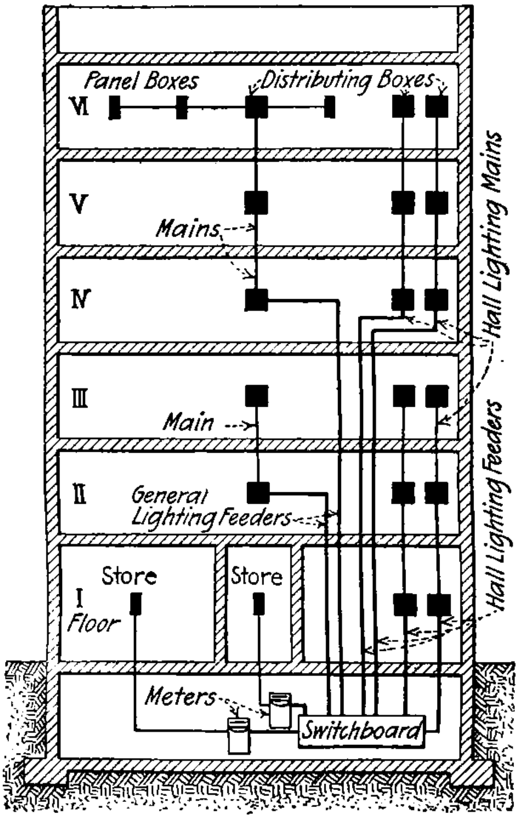


FIG. 255.—Two sets of lighting feeders.

one feeder (Figs. 254 and 255). Where it is not necessary to separately control the loads on the different floors and where the conductor size will not be prohibitively large, the cheapest and probably the best arrangement is to serve several or possibly all floors with one feeder. Usually the only limit to the number of floors that may be served with one feeder is the refinement of control that is required from the main switchboard. It is frequently necessary to make several tentative lay-outs and computations before the most desirable arrangement is found. Make a tentative arrangement of mains and feeders and compute the conductor

sizes by rules given elsewhere. If the tentative scheme does not prove satisfactory lay out another and try that. Motors, and groups of motors, unless very small, should be served by independent feeders.

343. Examples of feeder, main and panel-box lay-outs in large buildings are shown in Figs. 253 to 257. These are shown to illustrate principles rather than actual installations but each method shown could be effectively applied in some certain case. Elevator shafts often provide excellent runways for vertical, conduit-encased feeders. Mains and feeders should be installed of a size 25 per cent. larger than actually necessary to provide for growth. It is good practice to arrange to install feeders and mains in conduit even if the other conductors are run open.

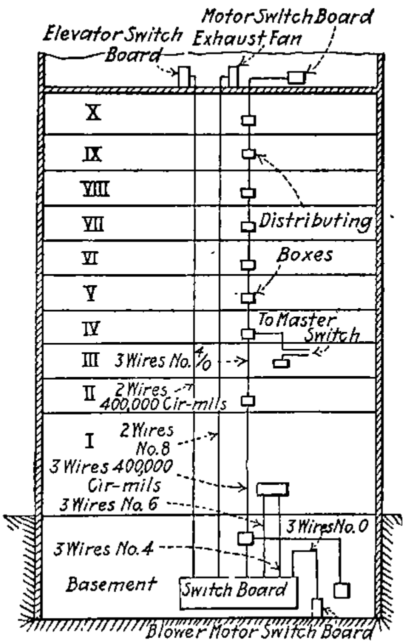


FIG. 256.—An actual feeder lay-out.

344. Feeders and Mains to the Floors of Buildings.—In buildings covering large areas, several panel boxes per floor may be required. These panel boxes may each be served by a separate riser if vertical wire ways are convenient (Fig. 257) or it may be better to install but one riser to each floor and distribute through horizontal mains to the panel boxes on the floor as in Fig. 254. In an installation where the feeders and mains are all vertical there need be no feeder runs in the floors. The construction of the building and the flexibility of control desired largely determine these points. An excellent arrangement is one with a feeder to each floor, Fig. 253, wherein flexibility of control and good voltage regulation are assured. The method of Fig. 254, one feeder serving three or more floors, is probably most often used. It costs somewhat less than the feeder-per-floor method, but does not provide equal flexibility of control nor quite as good voltage regulation. The feeder and main arrangement of Fig. 255 will also give good results if the main connecting the distribution boxes is made of the same size wire throughout, thus avoiding the installation of fuses in series. (See a discussion of this matter, as applied to the mains connecting a number of panel boxes on the same floor, which is given in a following paragraph.) Sometimes a single main is made to serve all the panel boxes in a building as in Fig. 256, but as a general proposition this places "too many eggs in one basket" and results in inflexible control. Any particular case must be decided on the basis of cost and merit.

345 **Distribution to Panel Boxes on Floors.**—(See above paragraph.) Often in buildings covering a small area one panel box per floor for general lighting is sufficient. Fig. 253, floors *V* and *IV* show an arrangement of mains from the distributing box to the panel boxes that may be used where the distributing box is located at about the center of the building. The lay-out on floor *V* is the best because with it trouble is localized, and very uniform pressure at panel boxes is assured. Where, as shown in *V*, subdivided mains are used the conduit for them will be small and can be readily installed within the floors. The method of *IV* is cheaper than that of *V* but the disadvantage is that fuses are required in series in the mains at each point where the wire size changes. The mains can be made the same size throughout at increased cost and fuses thereby avoided. (See information on mains and tapered mains in Sect. II of this book.)

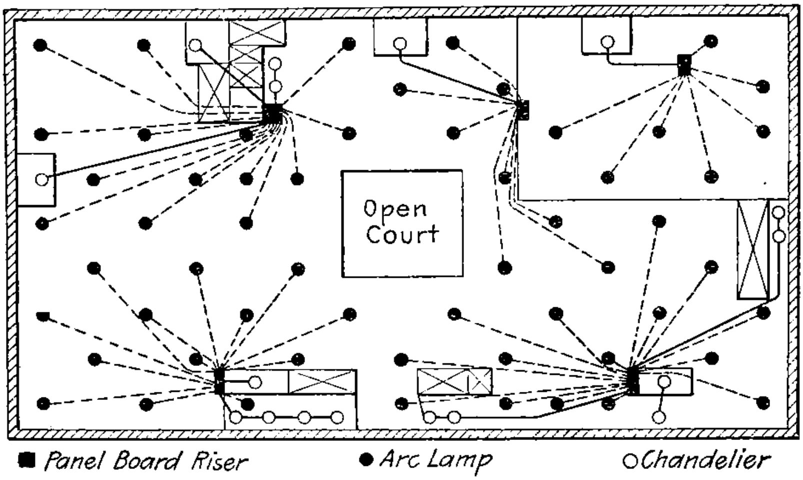


FIG. 257.—Arrangement of panel boxes on one floor.

Where the feeder to a floor rises at one side of the building the mains from the distributing box to the panel boxes may be arranged as in Fig. 254, floors *IV*, *V* and *VI*. The lay-out of *VI* is objectionable because there must be a fuse in series with the main in every panel box. By using two-wire sizes as in *V* instead of four the number of series fuses is reduced to two. The best arrangement is that of *IV* because with it there are no series fuses and troubles are localized. Fig. 257 shows a lay-out on a floor that is served by four panel boxes, each fed by a vertical riser.

346. **Shop Wiring Design.**—The design of the conductor system between the generating station and the shop buildings of an industrial plant that generates its own power is treated in another section and a general comparison of the distribution methods that may be involved is there given. The wiring for the lighting circuits within the shop is laid out on the same general basis as for other buildings as herein outlined. The lighting, feeder, main, distribution center and panel box lay-outs are about the same as

for other buildings. For groups of motors, circuits independent of the lighting circuits should be provided unless the motors are very small. These independent circuits should extend preferably from the generating station or at least from the entrance through the building to points wherever there are motors.

In general, the factors affecting the design of interior feeder and main lay-outs for power circuits are the same as given in Paragraph 336. Often in a one-story shop or on each of the floors of a several story shop the best method of serving the motors is to carry a single main the entire length of the shop. The motors can then, through fuses and switches, be connected to this main. A single main on each floor suffices for a narrow shop. Where the shop is wide, several parallel mains so located that no motor is very far from some one of them may be installed. Often a ring main running around just inside of the shop walls (see Fig. 124 Par. 233) provides a good arrangement. The branches from the main can be carried down the walls and under the floor to the motors. In a shop of several stories, unless the motor load is very small, it is a good plan to run separate power mains from the entrance to the building to each floor but any of the feeder and main arrangements shown for lighting circuits in Figs. 253 to 256 can be used. However the lay-outs for power conductors should be, and usually are, much more simple than those for lighting conductors. A simple arrangement is usually possible because a close voltage regulation is not so important with power as with lighting circuits.

347. Wiring for Electrical Distribution in Industrial Plants.—Standard practice of one large concern is described by Geo. R. Terry, in *Electrical World*, June 23, 1912. With large motors, each of which takes a considerable percentage of the energy transmitted over a main, separate motor and lighting mains are preferable. But with many small and mixed sizes of motors which are liable to removal and which consume a relatively small proportion of the power of the mains, one system of feeders and mains for motors and lamps appears to work out to greater advantage as any one motor is seldom large enough to cause interruption of service on the mains.

The feeders are carried through buildings on roof trusses supported on porcelain cleats, strain insulators being used at turns and ends. The cleats merely hold the conductors in line and out of contact with the trusses. When circuits pass through the yards from building to building they are carried on glass insulators supported on steel bents attached to the building side walls or roofs. The general rule for work inside of buildings is to run all circuits of wires larger than No. 8 B. & S. gage open above the roof truss line and in conduit below. All circuits of No. 8 and smaller wire are always in conduit.

INTERIOR WIRING COSTS

348. Cost of Interior Wiring (*Lectures on Illuminating Engineering*, Johns Hopkins University, October and November, 1910).—Prices of labor and material differ in different localities and at different times. It is, therefore, difficult to state even approxi-

mately what the cost of interior wiring for lighting should be. In large cities, these variations are not extreme and it is possible to state the limits within which the cost, expressed in terms of the usual contractor's price per outlet, should lie. The figures given below apply to interior wiring of all classes, from the small residence up to the large hotel or office building. They cover the portion of the work from the main source of supply, assumed to be at the building line. In case the building is lighted from its own plant these figures will apply to the portion of the installation lying between the lamps and the plant switchboard. No lamps, fixtures or reflectors are included in these prices which are for work installed as building is being constructed:

Exposed wiring, \$1.50 to \$1.60 per outlet.

Wire in wooden molding, \$2.00 to \$2.50 per outlet.

Concealed knob and tube wiring, \$2.50 to \$3.00 per outlet, with \$1.00 added per switch outlet.

Wiring in iron conduit, \$4.50 to \$5.00 per outlet.

Wiring in iron conduit in concrete buildings, \$5.00 to \$6.00 per outlet.

In the above, switches and base-board plugs are considered as outlets when the iron box is included. If the switch and plate are also to be furnished, approximately \$1.00 per outlet of this nature should be added. For the larger installations in modern buildings the price of \$7.00 per outlet, including all wiring and feeders up to the lighting fixture, has been found to be a fairly close figure.

348A. Knob and Tube Wiring In Finished Buildings

PRICES TO CONSUMER FOR DIFFERENT NUMBERS OF OUTLETS, SINGLE FLOOR CONSTRUCTION

No.	Cost	No.	Cost	No.	Cost	No.	Cost	No.	Cost
5	\$15.85	17	\$37.40	29	\$57.20	41	\$77.82	53	\$100.82
6	17.85	18	39.05	30	58.85	42	79.75	54	102.85
7	19.85	19	40.70	31	60.50	43	81.75	55	104.77
8	21.85	20	42.35	32	62.15	44	83.60	56	106.70
9	23.85	21	44.00	33	63.80	45	85.50	57	108.62
10	25.85	22	45.65	34	65.45	46	87.45	58	110.55
11	27.50	23	47.30	35	67.10	47	89.37	59	112.47
12	29.15	24	48.95	36	68.75	48	91.30	60	114.40
13	30.80	25	50.60	37	70.40	49	93.22	....	....
14	32.45	26	52.25	38	72.08	50	95.15	....	....
15	34.10	27	53.90	39	73.97	51	97.07	....	....
16	35.75	28	55.55	40	75.90	52	99.00	....	....

Add as per following for outlets under other than single floors and for hardware and drop cords.

Under double flooring otherwise than hardwood. Second or third story.

Ceiling outlet.. \$1.00 extra.

Switch outlet for any center outlet.................... 1.00 extra.

Under hardwood flooring, single, double or triple. Second and third story.

Ceiling outlet.. \$3.00 extra.

One switch outlet for any center outlet................. 3.00 extra.

Additional on same gang for same center outlet......... 1.50 extra.

Switches, hardware and drop cords as per following:

Push button switches, each	$1.00 extra.
Push button 3-way switches, per set of two switches	2.75 extra.
Porcelain base switches, each	.35 extra.
Porcelain base Edison receptacles, each	.35 extra.
Baseboard flush plate receptacles, each	1.15 extra.
Drop cord, key sockets each	.60 extra.
Drop cord, chain sockets, each	.75 extra.

Above from tables prepared for use of new business solicitors by the Central Station Development Company, of Cleveland, Ohio.

349. Prices of Wiring Old Buildings—Cottages.—(Commonwealth Edison Co., Chicago. From *Data*, November, 1911.) The prices are those charged the customer. This list is called special schedule "E" and is for 1-story cottages with open attic.

Seven to twelve lights	$35.00
Thirteen lights	39.00
Fourteen lights	41.00
Fifteen lights	43.00
Sixteen lights	45.00
Seventeen lights	47.00

Prices of wiring for switches and receptacles as given in **352** must be added. Prices of fixtures not included. The prices are based on concealed flexible conduit work, except in basement where rigid conduit is used.

350. Prices of Wiring Medium Grade Old Buildings.—The following prices are those charged the customer by the Commonwealth Edison Co., Chicago, and published in *Data*, October, 1911. The prices are for lamp outlets in flats of semi-fire-proof construction, renting for from $25.00 to $40.00 per month and in houses renting for from $20.00 to $50.00 per month. Schedule applies only to old houses having double floors of hardwood on pine. Prices of wiring for switches and receptacles from **352** to be added to the list prices. Prices are based on concealed flexible conduit work, except in basement where conduit is installed exposed on the ceiling.

Lights	Cost		Lights	Cost		Lights	Cost	
	Class "A" building 2 story	Class "B" building 3 story		Class "A" building 2 story	Class "B" building 3 story		Class "A" building 2 story	Class "B" building 3 story
10	$50.00	$70.00	28	$92.00	$116.00	46	$138.00	$173.50
11	52.00	72.00	29	94.00	118.00	47	140.00	176.50
12	54.00	74.00	30	96.00	120.00	48	143.00	179.50
13	59.00	81.00	31	98.00	122.00	49	148.00	186.50
14	61.00	83.00	32	100.00	124.00	50	151.00	190.00
15	63.00	85.00	33	102.00	126.00	51	154.00	193.50
16	65.00	87.00	34	104.00	128.00	52	157.00	197.00
17	67.00	89.00	35	106.00	130.00	53	160.00	200.00
18	69.00	91.00	36	108.00	132.00	54	163.00	203.00
19	71.00	93.00	37	113.00	143.00	55	166.00	206.00
20	73.00	95.00	38	116.00	146.50	56	169.00	209.00
21	75.00	97.00	39	119.00	150.00	57	172.00	212.00
22	77.00	99.00	40	122.00	153.00	58	175.00	215.00
23	79.00	101.00	41	125.00	156.50	59	178.00	218.00
24	81.00	103.00	42	128.00	159.50	60	181.00	221.00
25	86.00	110.00	43	130.50	162.50	61	186.00	226.00
26	88.00	112.00	44	133.00	165.50	62	189.00	229.00
27	90.00	114.00	45	135.50	168.50	....	....	....

351. Cost of Wiring High-grade Old Buildings.—Prices charged the customer by the Commonwealth Edison Co., Chicago. From *Data*, November, 1911. The prices are for lamp outlets in high-class apartments and medium-sized residences with hardwood finish throughout, renting for $50.00 per month. Prices of fixtures not included. Prices of wiring for switches and receptacles from 352 must be added. Prices are based on concealed flexible conduit work in buildings with a hardwood floor over one of pine.

Lights	Cost		Lights	Cost	
	Class "C" building 2 floors	Class "D" building 3 floors		Class "C" building 2 floors	Class "D" building 3 floors
10	$ 75.00	$ 88 00	36	$161.00	$182.00
11	78.00	91.00	37	166.00	189.00
12	81.00	94.00	38	169.50	193.50
13	89.00	99.00	39	173.00	198.00
14	92.00	102.00	40	176.50	202.50
15	95 00	105.00	41	180.00	207.00
16	98.00	108.00	42	183.00	211.00
17	101.00	111.00	43	186.00	215.00
18	104.00	114.00	44	189.00	219.00
19	107.00	117.00	45	192.00	223.00
20	110.00	120.00	46	195.00	227.00
21	113.00	123.50	47	198.00	231.00
22	116.00	127.00	48	201.00	235.00
23	119.00	130.50	49	206.00	242.00
24	121.00	134.00	50	210.00	246.50
25	126.00	141.00	51	214.00	251.00
26	129.50	145.00	52	218.00	255.50
27	133.00	149.00	53	222.00	260.00
28	136.50	153.00	54	226.00	264.50
29	140.00	157.00	55	229.50	268.50
30	143.00	161.00	56	233 00	272.50
31	146.00	164.50	57	236.50	276.50
32	149 00	168.00	58	240.00	280.50
33	152.00	171.50	59	243.50	284.50
34	155.00	175.00	60	247.00	288.50
35	158.00	178.50	....	....	....

352. Cost of Wiring Old Buildings—Switch Outlets, Switches and Extras.—The following prices to the customer are those of the Commonwealth Edison Co., Chicago (*Data*, Nov., 1911) and are to be added to the price given for outlets in the three preceding tables. Wiring is concealed and in flexible conduit.

Cost of wiring for switch outlets					
Class	A	B	C	D	E
Single pole.	$3.00	$3.50	$4.25	$4 50	$2 50
3-way..............	4.50	5.00	5.75	6 00	4.00

In addition to the above prices for wiring switches, additional prices for switches, etc., will be as follows:

Flush push button single pole	$1.00	Drop cord (without canopy)..	.75
Standard snap single pole....	.50	Water-proof floor receptacle.	3.00
Automatic door switch......	1.50	Flush baseboard receptacle...	1.50
3-way flush switch..........	1.00	Standard wall socket........	.50
3-way snap switch..........	.50		
Drop cords, including spun brass canopy cord, and socket	1.00		

353. Cost of Knob-and-Tube and Conduit Work.—Work done in St. Paul, Minn. Costs are those to the customer and are for new work. (*Electrical World*, Jan. 28, 1909.)

Job number	Knob-and-tube			Iron conduit	
	Number of outlets	Total cost	Cost per outlet	Total cost	Cost per outlet
1	120	$247.00	$2.06	$423.00	$3.53
2	80	147.00	1.84	251.00	3.14
3	72	158.00	2.19	248.00	3.44
4	66	136.00	2.06	213.00	3.23
Average	....	....	2.04	....	3.26

Average excess cost of conduit above knob-and-tube work is 60 per cent.

354. A day's work for a wireman and helper in erecting molding, on surfaces where holes must be drilled and plugged to support it, is the running of 100 ft. (Auerbacher).

355. The division of cost of a conduit job will be approximately as follows: Labor, 40 per cent.; conduit, 22 per cent.; wire, 18 per cent., and incidentals, switches, outlets, etc., 20 per cent. (*Electrical World*).

356. Cost of double-braided rubber-insulated wire in place in conduit. (*Nelson S. Thompson*, *Electrical World*, Sept. 9, 1911.) Costs do not include conduit.

Single conductors			
Size A.W.G.	Cost per 1,000 ft.	Size A.W.G. & cir. mils	Cost per 1,000 ft.
Solid		Stranded	
16	$15.00	1	$101.30
14	18.60	0	128.00
12	21.70	00	156.00
10	25.85	000	184.25
Stranded		0000	217.00
8	35.40	250,000	275.00
6	48.25	300,000	327.00
4	62.65	400,000	405.00
3	75.25	500,000	500.00
2	82.00		
Duplex conductors			
14	$30.00	10	$40.25
12	34.00	8	49.25

357. Cost of Conduit in Place (New Building)

½ in. size	$ 8.50 per 100 ft.
¾ in. size	10.25 per 100 ft.
1 in. size	13.75 per 100 ft.
1¼ in. size	18.25 per 100 ft.
1½ in. size	22.00 per 100 ft.
2 in. size	30.60 per 100 ft.
2½ in. size	47.00 per 100 ft.
3 in. size	60.00 per 100 ft.

358. Cost of Conduit Elbows in Place

2 in. size	$ 1.00 each
2½ in. size	1.25 each
3 in. size	4.00 each
4 in. size	10.00 each

359. Estimating Costs of Conduit Installations.—The Treasury Department of the United States uses the following methods and values for computing the costs of conduit wiring in federal buildings. (*Nelson S. Thompson*, *Electrical World*, Sept. 9, 1911.) The figures are for high grade work in fire-proof buildings. The material is taken off accurately from the drawings. The total amounts of conduit and wire are the lengths scaled from the plan plus the following: Number of ceiling outlets×2 ft.; number of bracket outlets×10 ft.; number of switch outlets×10 ft.; number of baseboard outlets×4 ft.; number of two-gang switches×15 ft., and number of three-gang switches×20 ft. Table 357 shows the cost of conduit in place. For the cost of underground service connections in place and for work in old buildings where walls and ceilings are cut and plaster must be replaced, 50 per cent. should be added to the tabulated values.

The cost of all kinds of outlet boxes in place is 25 cents each in new buildings and is 50 cents in old buildings where plaster must be repaired. The cost of large junction boxes in place is 5 cents per pound. Plug receptacles in place cost $1.30 each. Single pole snap switches in place cost $1 each. Fixture studs cost 5 cents each in place; outlet bushings 5 cents each in place; lock-nuts 1 cent each in place. One should estimate 3 bushings and 3 lock-nuts per outlet.

The average total cost of lighting systems complete in place in eastern sections of the country is about $12 per outlet; in the West and South the cost will be about $15 per outlet, and in the extreme West the cost per outlet will be $20. The number of outlets upon which these figures are based does not include switch outlets, but only the actual lamp outlets. In old buildings the cost of the conduit and wiring work is $20 to $25 per outlet and $30 in the extreme West.

360. Miscellaneous wiring costs for first class conduit work in fire-proof buildings. (*Nelson S. Thompson*, *Electrical World*, Sept. 9, 1911.) Busbars for switchboards, in place 50 cents per pound; structural steel work, in place, for switchboards, 10 cents per pound; blue Vermont marble, 2 in. thick, $2 per square foot; slate panels, 1¼ in. thick, 50 cents per square foot; drilling holes, slate and marble, 25 cents each; labor on switchboard panels in

shop, \$25, and on the job, \$12 each; tablets and cabinets, complete in place, \$5 per switch. One should ascertain if possible the actual cost of cabinets and tablets and add \$1 per circuit for installation. Standard floor outlet boxes (such as are used in United States federal buildings) cost \$3 each in place; telephone cabinets in place (such as are used in federal buildings) cost \$20 each.

Motor connections, 5 h.p. and under, \$2 per horse-power; motor connections, 10 h.p. up, \$1 per horse-power; freight and drayage, 3 per cent. of total cost of material and labor; railroad fare, depending on location of the job; board and lodging, depending on location of the job; superintendence, 1 per cent. of total cost of materials and labor, and profit, 20 per cent. of total cost of materials and labor.

ELECTRIC SIGN WIRING

361. Methods of Wiring Electric Signs (*Data on Electric Signs*, The National Electric Light Association).—Lamps burning in multiple may be connected either two-wire or three-wire, as shown in Fig. 258. In series wiring, lamps may be connected either in straight series or multiple-series, as shown. Where transformers

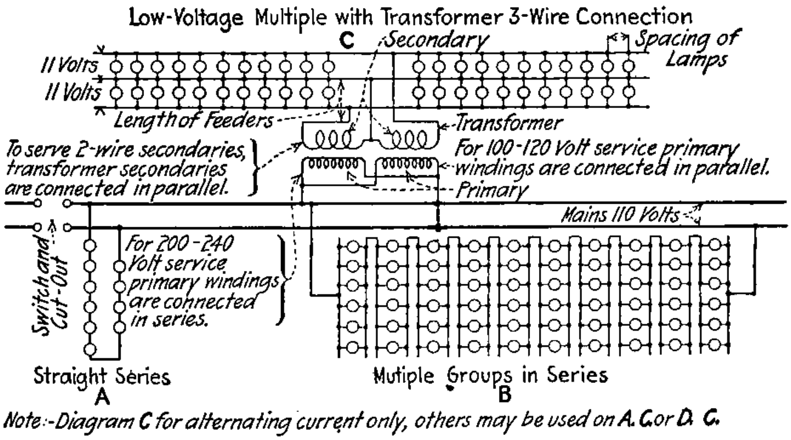


FIG. 258.—Methods of connecting sign lamps.

(see section on Transformers for information on sign transformers) are used to obtain low voltage, lamps may be connected either two-wire or three-wire as in standard multiple wiring, the transformer reducing the voltage from the regular 110- or 220-volt circuits to the voltage required by the lamp. The ordinary multiple wiring can be changed to straight series wiring by merely clipping the alternate connections between lamps (Fig. 259).

In a large sign any combination of series or multiple-series may be used. With straight series wiring, should one lamp in the series burn out, all the lamps in that series will be out. If the lamps are connected in multiple-series, the failure of one lamp does not cause any of the other lamps to go out. However, there

should be not less than eight to ten lamps in each multiple group or the failure of one lamp will cause too much current to flow through the other lamps of the same group, thus shortening their lives.

362. Sockets for Electric Signs.—Any standard weather-proof socket manufactured for sign use is satisfactory providing it has been approved by the Underwriters and has been shown to be thoroughly weather-proof. A socket with an extending porcelain cap which protects the base of the lamp from water is desirable

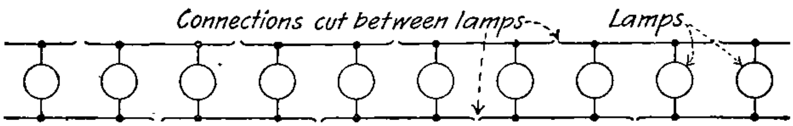


FIG. 259.—Method of changing sign wiring from multiple to series.

in that it gives a longer life to the lamp. A removable copper shell is desirable inasmuch as there is a certain amount of wear from the taking of the lamps out of the sign for cleaning or renewing, and as the workmen are in the air, they cannot be as careful as they would be under ordinary conditions and the copper shell is often torn. If the copper shell cannot be removed from the front of the socket, it is necessary to open up the sign to make repairs, while if the shell can be removed, a new one can be put in at small expense.

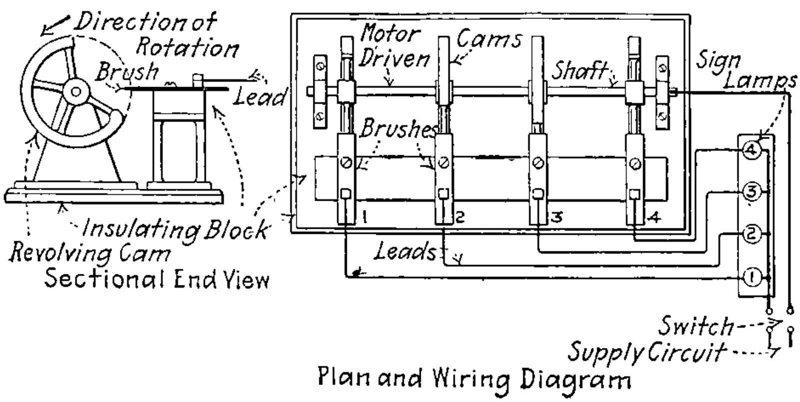


FIG. 260.—The elementary sign flasher.

363. The principle of the sign flasher is illustrated in Fig. 260. Cams or a drum are mounted on a shaft that is rotated by a small electric motor. The circumferences of the cams or of the drums are so cut that, in the brush-type flashers, the brushes will make contact only during certain predetermined portions of a revolution and thereby complete the electric circuit through the sign lamps only during that period. In the carbon-type flashers the cams, instead of carrying current and making and breaking the contacts directly, operate to open and close carbon-break knife

switches which control the sign lamps. The possible variations in arrangement of cams and drums for producing different effects are almost numberless.

364. Current Carrying Capacities of Flashers.—Double-pole flashers are made in four sizes that will carry respectively 15, 30, 45 or 60 amp. per switch. Single-pole carbon flashers are made that will carry 5 amp. per switch. Brush type flashers are rated at from 2 to 5 amp. on each brush and are not reliable for greater currents. Non-carbon, double-pole-switch flashers are made for currents of 15 amp. and greater but it is claimed by some manufacturers that 15 amp. should be the maximum because no knife switch can successfully break greater currents continuously.

365. Wiring and Installing Brush Type Flasher.—Fig. 261 shows the wiring for a sign for "spelling" out. The neutral wire

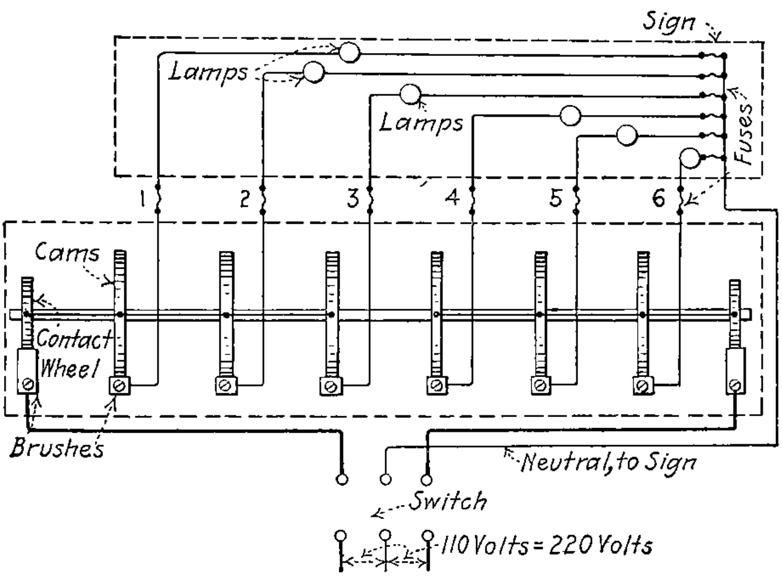


FIG. 261.—Wiring of three-wire brush-type flasher.

(or one main on a two-wire system) runs direct to the sign through the customary cut-outs, and the outside "legs" (or remaining main on a two-wire system) run to the flasher as a common feed. From the flasher one wire is run to each individual letter through the customary cut-outs. In the case of a double face sign, two like letters can be connected in multiple and regarded as one circuit, provided the load which one switch of the flasher is designed to carry is not exceeded.

Always install so that the copper brushes are at the front of the flasher. Follow the general installation directions given for carbon flashers in another paragraph.

366. Wiring diagrams for carbon sign flashers (*Reynolds Dull Flasher Co.*, Chicago) are given in Fig. 262. Unless otherwise ordered flashers are furnished requiring a wiring arrangement like

that at *III*. The load is balanced by running the neutral around the machine, to the cut-outs, breaking only the outside "legs" on a 220–110-volt system. While this method of wiring is entirely feasible, is no harder on the contacts, and permits the use of a cheaper flasher, it is technically a violation of the insurance rules, which specify that all circuits of more than 660 watts must be broken double pole. If the load is absolutely balanced it would break double pole at 220 volts, and the lamps would be in series, but if the load is not exactly balanced there would be single-pole breaking. In other words, it is a double break and again it is not, according to circumstances. The use of this machine wired in this way should be taken up with the local inspector. If he is disposed to take a broad view of the matter he will undoubtedly permit

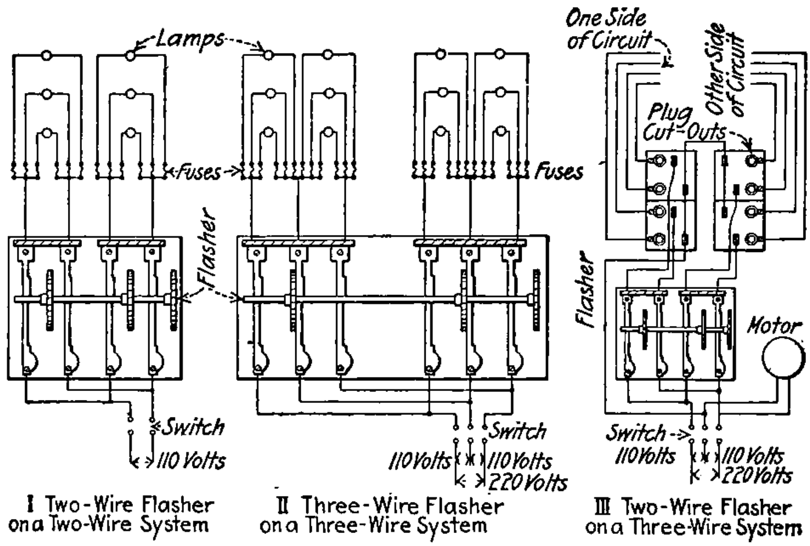


FIG. 262.—Wiring diagrams for carbon sign flashers.

its use, as it is just as safe as any other way, but if he should insist on an absolute observance of the code, it is probable that he would not permit it.

367. In installing and wiring a carbon flasher (*Reynolds Dull Flasher Co.*, Chicago) run the mains to the upper bridge of the flasher, and run the sub-mains to the sign and to the terminals on the base of the machine. The sub-mains are divided into the small circuits either in the sign or as close thereto as possible to save the cost of wiring. Each small circuit into which the sub-mains are divided should be protected with fuses and some inspectors may require that the sub-mains also be protected with fuses where they leave the flasher.

Place the flasher on a wood shelf, 15 in. wide and 10 in. longer than the slate base, in such manner that the carbons are in the front, the motor at the left with the commutator side to the front. The shelf should be covered with asbestos and if the machine is in a basement or out of sight, cover it with an iron or fire-proof

box and if to be run in plain view, it should be covered with a glass case. Run all wires through bushings in the shelf close to the base of the machine.

Do not screw either flasher or motor down tight but leave an eighth of an inch clearance under the heads of the screws. The top of a show window, a board partition, or anything that acts as a sounding board will increase the noise three-fold and when it is necessary to install in such places, arrange an extra set of rubbers under the shelf also.

368. Some "Dont's" to Observe in Installing Sign Flashers (*Reynolds Dull Flasher Co.*).—DON'T start the flasher without examining it for damage in transit. Give a few turns by hand and see that everything works perfectly free and easy and that the blades fit into the forks properly.

DON'T install the flasher in the bottom of a box where it is not accessible. Place it on a shelf, run the wires down through the shelf close to the base and turn a cover upside down over it.

DON'T install hind-side foremost. The carbons should always be to the front.

DON'T run with a tight belt. Practically no power is required. Run the belt just as loose as it will stay on.

DON'T run your flasher backward. Looking at it from the switch side, the main shaft should run from you on the top.

DON'T run the flasher over ten revolutions per minute nor less than six.

DON'T fail to instruct your customer about oiling.

DON'T connect up a carbon machine single pole.

DON'T overload any switch on a flasher.

369. Wiring for the so-called "high-speed" effects (*Reynolds Dull Flasher Co.*, Chicago) such as running fountains, rising smoke,

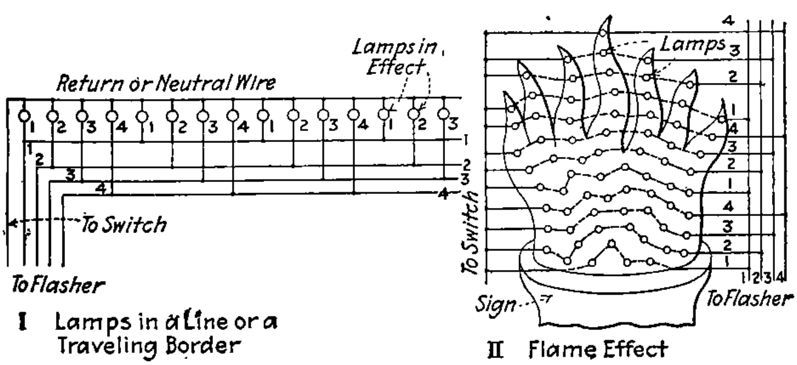


FIG. 263.—Wiring of "High-speed" effect signs.

flames, traveling borders and revolving wheels are wired as indicated in Fig. 263. The diagram at *I* is for the effect where the sign lamps are in a single line and the same general arrangement is used for a traveling border. For a fountain effect number the lamps at the beginning of each stream and so continue to the end of the stream and where several streams run parallel all the lamps

in one horizontal row can be connected to the same branch as though they were one lamp. Traveling borders on an ordinary 3 ft.×10 ft. sign should have lamps spaced about 6 in. apart. In a fountain 15 ft. high the lamps should be about 9 in. apart. Fig. 263, *II*, shows the wiring diagram for smoke, flame, steam, dust and running water effects. Avoid a "straight-across" arrangement of lamps as the resulting effect will be unnatural.

370. The wiring for a flashing illuminated sign, that is, a painted sign which is successively illuminated (by lamps carried in a reflector trough above it) and darkened by the lamps being extinguished is shown in Fig. 264. Lamps should be 16 c.p. and mounted not more than 12 in. apart in the reflector which should preferably be of the silver backed type. For flashing in colors but three can be used, namely: red, clear and amber. Other colors such as green, blue, etc., are too dense to produce a good effect and little light will throw down more than 8 ft. A carbon type flasher should be used.

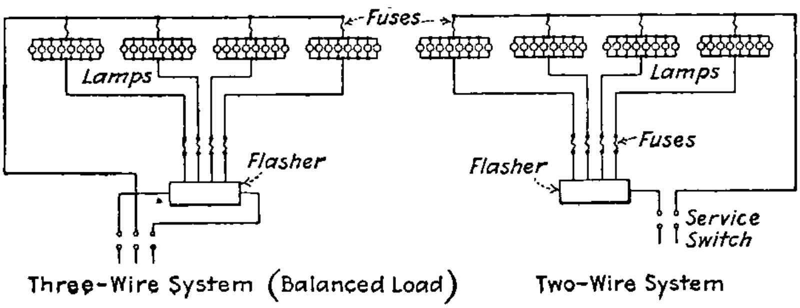


FIG. 264.—Wiring for flashing sign.

371. Regulations for the erection of electric signs as given in the *Rules and Regulations of the Commonwealth Edison Company*, Chicago, are as follows:

Accessibility.—Signs which are to be cleaned or re-lamped from a ladder must not be hung higher than 30 ft. above the sidewalk. All signs placed at a greater height must be so located and hung that they may be swung in toward the building both ways and reached from the windows. Such signs shall be so placed that the bottom of the sign shall not be below the window sills from which it is to be cleaned, and the top of the sign shall not be more than 6 ft. above the window sill.

Guy Lines.—Any sign which must be cleaned or re-lamped from a ladder, and whose top is more than 18 ft. above the sidewalk, shall be provided with two sets of guy lines having separate attachments on sign and on building. All guy lines, whether of chain or cable, shall be hot galvanized. Sectional signs, provided with two sets of guy lines, shall have one set attached to the bottom of the sign and the other set attached to the top of the sign. Guy lines shall be placed at such an angle with the horizontal that the signs will not be raised up and the weight taken from the main supporting chain by strong wind.

Strong Backs.—In case it is not convenient to provide a sign with guy lines on each side, the sign shall be held rigid from swinging by means of a stiff rod or strong back connected to the top of the sign.

Expansion bolts shall be of the lead wedge expansion type, $\frac{5}{8}$ in. in diameter by 3 in. long, and shall be firmly set in holes drilled into a masonry wall. If the wall is of brick, the hole shall be in the center of a hard, firm brick. All soft or loose bricks must be avoided. If a solid brick cannot be found, the guy line must be attached to a bolt passing through the building wall.

Turnbuckles.—Eye bolts and hooks which screw into turnbuckles shall have holes drilled through their ends and shall be provided with a split pin to prevent unscrewing.

Hinge Bolts.—Hinge bolts shall be provided with lock nuts or split pins.

Bushings and Collars.—Swaying signs shall be attached to their cranes by hangers passing over iron collars placed on the crane and provided with an aluminum lining. A bearing for these aluminum-lined collars shall be placed upon the crane, and shall consist of solid aluminum collars with flanges at one end. The aluminum collars shall be placed upon the crane with the unflanged ends facing each other, and shall be rigidly attached to the crane and be of such size that the aluminum-lined iron collars shall have a snug fit, but be free enough to permit the sign to oscillate.

Cross Plates.—Cross plates to which guy lines are attached shall be bolted to the sign with two short, snug fitting bolts, which shall be riveted over after nuts are put on. These bolts shall be large enough to support the sign without danger of breaking or shearing, and shall not be smaller in diameter than ⅜ in. The plates shall be of such a width that the distance between bolts shall not be less than one-third the distance between the holes where the guy lines are attached.

Feed Wires.—Swaying signs supported from a crane shall have stranded feed wires between building and sign. Feed wires which are not run through the crane shall be attached to insulated support on the crane near its base, and from this support connect to the sign with a drip loop extending 3 in. below the sign outlet. Wherever feed wires pass through an iron plate or through the side of an iron pipe the opening shall be protected by a porcelain enameled bushing.

ELECTRIC HEATING DEVICE INSTALLATION

372. **Special outlets for heating devices** are frequently required. Outlet plates, similar to that of Fig. 265, provided with receptacle, switch and indicating lamp socket are regularly manufactured for currents as great as 20 amp. Keyless brass sockets have a maximum rating of 6 amp. The ordinary pull-chain and key sockets have a maximum rating of $2\frac{1}{2}$ amp. Standard separable attachment plugs are approved for 660 watts at 250 volts, or 10 amp. on a 110-volt circuit. Where ordinary key sockets are used for switching on and off heating devices they soon wear out under the action of the arcs formed in breaking the relatively heavy currents. Snap or knife switches should always be used for heating devices. Specially constructed, asbestos-covered, flexible cords are specified for all heating devices requiring more than 250 watts.

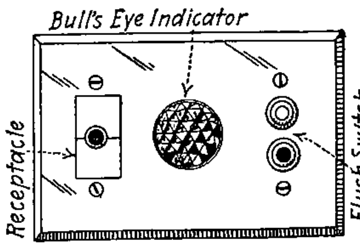


Fig. 265.—Indicating heater receptacle.

373. **An approximate rule for the wattage of an electric heater to heat a room** is to allow $1\frac{1}{2}$ watts of heater input (maximum) per cubic foot of air space for shops, factories, halls, churches and central stations and 2 watts per cubic foot of air space for average rooms. The direction of exposure, the number of windows and the quality of building construction, and other things, all have a bearing on the matter so the values given are approximate only for average conditions of building and climate.

374. Power and Current Taken by Heating Devices (*Electrical Solicitor's Handbook*

Domestic devices

Device	Watts consumed	Amperes taken at 110 volts
Broilers, 3 ht.	300 to 1,200	2.7 to 10.9
Chafing dishes, 3 ht.	200 to 500	1.8 to 4.6
Cigar lighters	75	0.7
Coffee percolators for 6-in. stove	100 to 440	0.9 to 4.0
Corn poppers	300	2.7
Curling-iron heaters	60	0.6
Double boilers for 6-in., 3 ht. stove	100 to 440	0.9 to 4.0
Flatiron (domestic size), 3 lb.	275	2.5
Flatiron (domestic size), 5 lb.	400	3.6
Flatiron (domestic size), 6 lb.	475	4.3
Flatiron (domestic size), 7.5 lb.	540	4.9
Flatiron (domestic size), 9 lb.	610	5.6
Frying kettles, 8 in. diameter	825	7.5
Griddle-cake cookers, 9 in. by 12 in., 3 ht.	330 to 880	3.0 to 8.0
Griddle-cake cookers, 12 in. by 18 in., 3 ht.	500 to 1,500	4.6 to 13.7
Heating pads	50	0.5
Instantaneous flow water heaters	2,000	18.2
Nursery milk warmers	450	4.1
Ovens	1,200 to 1,500	10.9 to 13.7
Plate warmers	300	2.7
Radiators	700 to 6,000	6.4 to 5.5
Ranges: 3 heats, 4 to 6 people	1,000 to 4,515	9.1 to 40.1
Ranges: 3 heats, 6 to 12 people	1,100 to 5,250	10.0 to 47.5
Ranges: 3 heats, 12 to 20 people	2,000 to 7,200	18.2 to 65.5
Shaving mugs	150	1.4
Stoves (plain), 4.5 in., 3 ht.	50 to 220	0.5 to 2.0
Stoves (plain), 6 in., 3 ht.	100 to 440	0.9 to 4.0

Commercial devices

Device	Watts consumed	Amperes taken at 110 volts
Annealing furnaces	200	1 .8
Bar or barber's urns, 1 to 5 gals., 3 ht.	200 to 1,700	1.8 to 15.5
Baker's ovens, 30 to 80 loaves	6,000 to 10,000	54.5 to 91.0
Cigar lighting	75	7
Dental furnaces	450	4.1
Glue pots	110 to 880	1.0 to 8.0
Hat irons (small)	200	1.8
Hatter's iron, 9 to 15 lb.	450	4.1
Instrument sterilizers	350 to 500	3.2 to 4.6
Laboratory apparatus flask heaters	500	4.6
Machine irons, 12 to 18 lb.	770	7.0
Pitch kettles, 12 and 15 in., 3 ht.	300 to 1,500	2.7 to 13.7
Polishing irons, 3.5 to 5.5 lb.	330 to 450	3.0 to 4.0
Radiators (various sizes)	700 to 6,000	6.4 to 54.6
Sealing-wax pots, 0.5 and 1.5 pt.	175 to 300	1.6 to 2.7
Shoe irons	200	1.8
Soldering irons (various sizes)	100 to 450	1.8
Soldering pots, 4 to 10 lb. capacity	200 to 440	0.9 to 4.0
Tailor's iron, 12 to 25 lb.	660 to 880	6.0 to 8.0
Vulcanizers for automobile tires	100 to 450	0.9 to 4.0

375. Luminous radiators or air heaters, which are sometimes called convectors, can be used for room heating. From the standpoint of energy utilization a heater of one type is as efficient as a heater as the other since in any electrical heating device all of the electrical energy put into it is transformed into heat. Luminous radiators, which throw off radiant heat, are suitable for quickly warming any portion of one's body. The radiant heat rays will warm only a material which is opaque to them. They pass through air without heating it and are not affected by air currents. They may heat air indirectly by heating objects in contact with air, the objects transmitting the heat to the air. As a general proposition luminous radiators are not suitable for warming large spaces.

Air heaters or convectors heat the air passing over the heated surfaces of the convector. Convectors should be so arranged that there is an effective circulation of air through and around them. A single, large capacity heater in a room will not heat it as effectively as several small capacity heaters having the same aggregate capacity. Heaters should be preferably placed under or near windows.

376. To estimate the wattage of an electric heater to heat a room the following approximate formula has been used. It is based on the assumption that the inside temperature is to be 70 deg. fahr. and the outside temperature is about 12 deg. fahr. below zero.

$$\text{Watts required} = 5S + 50W + 0.5A$$

Wherein, $S =$ sq. ft. of wall surface exposed exclusive of window surface, $W =$ sq. ft. of window or glass surface exposed, and $A =$ cu. ft. of air space in the room. Where the inside and outside temperatures vary much from those above assumed, the wattage required will be (approximately) correspondingly more or less in proportion to the difference between the inside and outside temperatures.

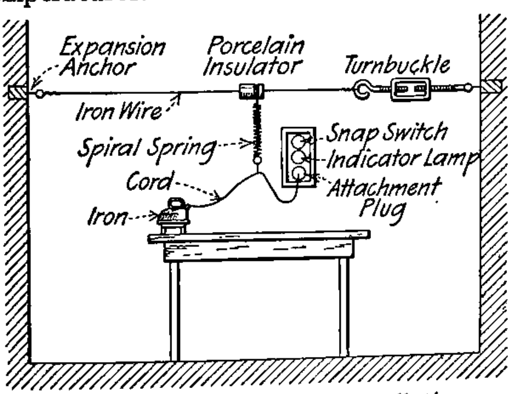


FIG. 266.—An electric iron installation.

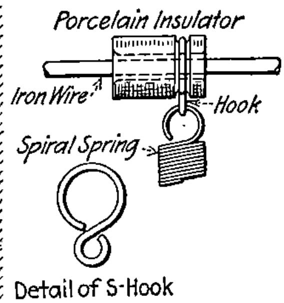


FIG. 267.—Method of supporting spring.

377. A method of supporting the conducting cord of an electrically heated iron (*Electrical World*, May 4, 1911) is shown in Fig. 266. The spring is fastened with an "S" hook (see Fig. 267) to a porcelain insulator which is arranged to slide back and forth

on a wire. As the iron is pushed to and fro the porcelain insulator follows its movements and, as the spring will stretch, ironing can be done over a considerable area. The conducting cord is supported well out of the way of the operator. Spiral springs are usually furnished by the manufacturers with all sadirons.

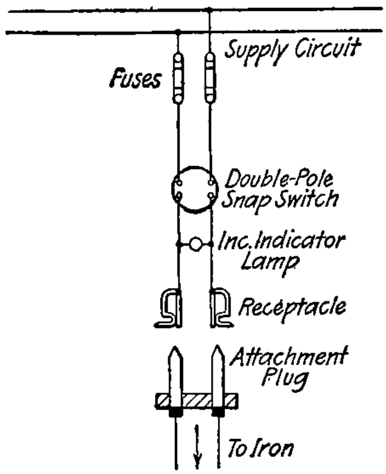


FIG. 268.—Wiring diagram.

The iron wire is made up in a screw eye, inserted in the wall at one end and into one eye of a small turnbuckle at the other end which provides means for keeping the wire tight. The hook end of the turnbuckle engages with a screw eye inserted in the wall. It is well to arrange the iron wire somewhat to the rear of the line along which the iron will be used. This is done to prevent the cord from striking the hand of the ironer.

378. **A method of wiring an electric iron** is shown in Figs. 266 and 268. An incandescent lamp of small candle-power is connected across the branch circuit to the iron on the iron side of the double-pole switch. So long as the switch is closed and the iron connected to the supply source the lamp will glow and indicate the fact that the iron is "alive." This device not only tends to make the operator careful in his use of energy, but it assists in preventing the fires that are sometimes caused by an electric iron being left on a wooden ironing board while connected to a supply source.

WIRING OLD BUILDINGS

379. **Information on Wiring Old Buildings.**—The information herein given on this subject is taken, for the most part, from a paper "*The Wiring of Old Houses*" read before the Pennsylvania Electric Association Convention, Bedford Springs, Pa., Sept. 3, 1912, by Howard H. Wood of the Allegheny County Light Company.

380. **In laying out old house wiring installations,** the first things to be considered are the location of the meter and the tablet board, and the point where the wires are to enter. The meter loop should generally be located in either the kitchen, pantry or cellar. In the smaller houses, the tablet board should be located near the meter, and in the larger houses, where there are a number of branch circuits, at the central point of distribution, *i.e.*, at some point on the second floor, preferably the hall. The point of entry should be located with reference to the accessibility of the service connection.

381. **Typical Wiring Plan of an Old Building.**—Fig. 269 shows the routes taken by the wires, to chandeliers and switches, within

walls and under floors. The point of entry for the mains in this case is the kitchen, on the outer wall of which is located the main switch, the fuse block, and the meter. The connected load being less than

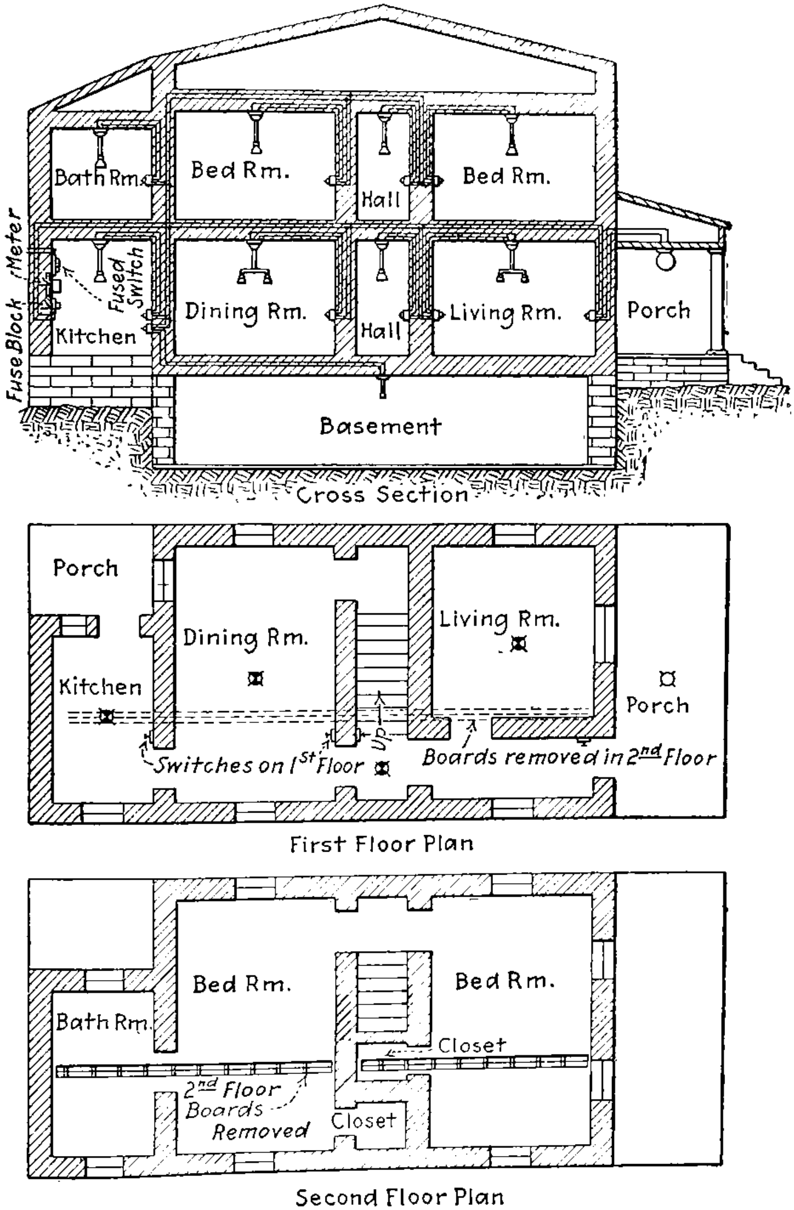


FIG. 269.—Wiring of a five-room house.

660 watts, or the equivalent of 12 lamp outlets, only one circuit is necessary. Double-pole switches are shown, as they are required in certain cities in installations where combination gas and electric

fixtures are used. Single-pole switches, installed in accordance with Code rules, are practically as good for the average installation. The methods of carrying conductors to single-pole switches will be obvious from a study of the illustration.

The dotted lines show the flooring boards taken up on the second floor, and the fixture and switch locations on the first floor are indicated. The switch locations are within easy fishing distance.

The flooring boards are removed on the second floor in such locations as to pass under one partition only, and with regard to accessibility of the outlet and switch openings below.

In many houses of the type shown, the space between roof and second floor ceiling is sealed, in which case a hole is cut in the ceiling of a closet, and the opening is provided with a trap door.

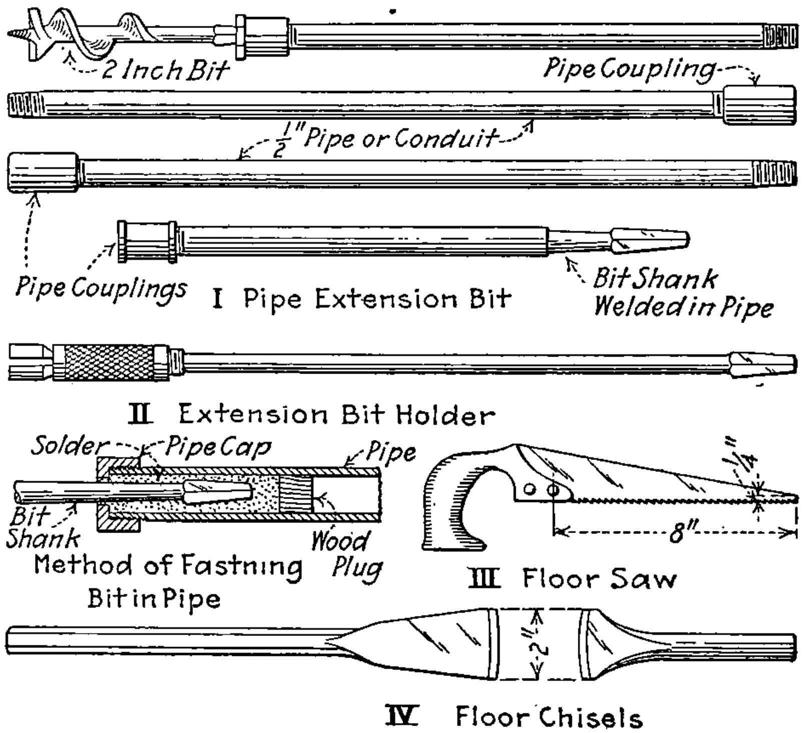


FIG. 270.—Tools used in wiring old buildings.

382. Special Tools Used in Wiring Old Buildings. (See Fig. 270.) (*a*) *Pipe Extension Bit.*—Used to drill through cross pieces or headers in a partition where it is impossible to get over or under them, as from the cellar up, and from the third floor down. A 2-in. bit is used, making a hole large enough to take four pieces of flexible tubing. Cases are known where boring has been done from the cellar to the third floor successfully, although the necessity for this is very rare. Fig. 271 illustrates the application of this device. A bit brace can be used for turning it or if the space is restricted a pipe wrench can be used.

(*b*) *Floor Saw.*—Used in removing flooring boards, made short enough so that it cannot be pushed through the plaster of the ceiling below. The blade is ¼ in. wide at the point and approximately 8 in. long with a handle similar to a key hole saw.

(*c*) *Floor Chisels.*—Used in removing the flooring boards. The chisels are from 12 to 24 in. long and 2 in. wide at the point.

(*d*) *Extension Bit Holder.*—Used in a bit brace for drilling holes in joist. They are 2 to 3 ft. long, and enable wireman to drill holes in a recess, or in places where a long bit would be needed. By coupling two of the holders together, the wireman can drill circuit holes in joist while standing, which renders the work much easier, where there are a number of holes to be drilled.

Mouse.—Used in locating cross pieces, and finding clear spaces in partitions. Is made up of a length of twine with a piece of lead or other heavy material on its end.

Snake.—Used in fishing wires through partitions or under floors; made of rectangular or round steel wire.

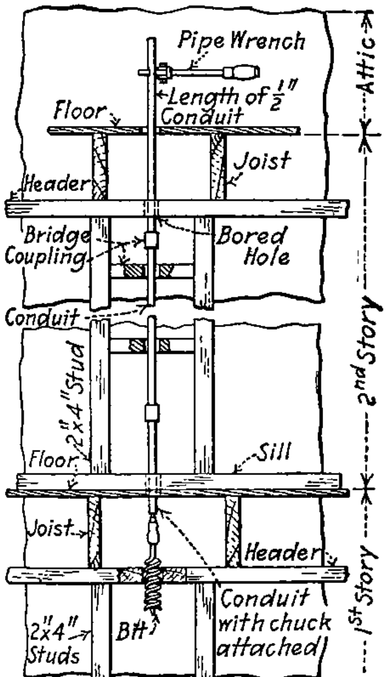


FIG. 271.—Illustrating use of the pipe extension bit.

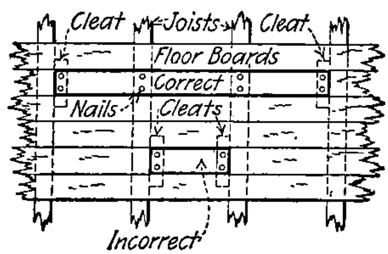


FIG. 272.—Methods of locating cleats to support floor boards that have been removed.

383. Removing Flooring Boards.—First a slot must be made in the seam between flooring boards of sufficient size to enable the floor saw blade (Fig. 270) to be inserted. This is best done with a sharp, narrow chisel having a ⅝-in. blade. Then the saw blade is inserted, and the tongue at the junction of the flooring boards is sawed off the full length of board to be removed. The wireman can tell when he reaches the joist at which he wishes to end his cut. At this point the chisel blade is placed, with the flat part across the board at edge of the joist, and another small slot made. Then the board is sawed off even with the joist, and can be easily removed with a floor chisel (Fig. 270). When the board is replaced, a cleat is nailed to joist (Fig. 272) for the board to rest on, and then the board is nailed down, or better yet, screwed

down, so that, if it is necessary to get at the wires again, it can be done with little trouble. When fastening down the flooring, two nails or screws should be put in each joist. When only one nail is used, the board is liable to squeak when walked over. To insure a substantial job, any floor board that is removed should be long enough to bridge at least two joists.

384. Fishing to Center Outlets.—A great deal depends on the layout of the house. Almost invariably the joists are run parallel to the street. If the house is one with a side or center hall on the second floor, the circuits can be run the length of the hall, necessitating the removal of two boards for that distance. Wires can then be fished from the center of the room by cutting a small hole at the chandelier location, or by cutting a pocket in the floor directly above the location of the outlet. If it is necessary to take up the boards in the floor at some distance from the partitions, another pocket will have to be taken up close to the partition in order to drop the switch loops, and to go through to the other side. This is necessary when the hall is in the center, with the rooms to be wired on each side.

If, as is the case with some of the smaller houses, there is no hall on the second floor, and the rooms are directly in the rear of each other, the boards can be taken up through the door-ways, and the wires dropped to the switches, outlets, and to the tablet board in the kitchen very readily. (See Fig. 269.) Where there are hardwood floors, the wires must be fished from the center of the room to a closet, or to a point where the baseboard can be removed, so as to get into a partition going either up or down. In a great many cases, it is necessary to drop to the cellar, and then come up again in another location for the switch loop. Where this is necessary, the most convenient place for the tablet board is in the cellar.

384 A. When plaster-of-Paris molding or center pieces are to be drilled, the Syracuse bit is the best. In many cases it is necessary to first saw off the lower portion of the center decoration to provide a flat surface to front the drill. Use very little pressure, and have the drill very sharp.

385. Wiring for Switch Loops.—In a great many cases, the bringing out of the switch loops at outlets at a proper distance from floor is the most difficult part of wiring old houses, on account of the cross pieces or bridges sometimes found in partitions. The method to be used must be determined by the wireman on the job, according to the conditions found. Following are some of the methods used:

First, with his mouse, he finds if the runway is clear; if so, the rest is easy. But, if he finds there are cross pieces, he locates their position by measurement with the mouse, and marks the location on the wall. If the cross pieces are above the proper positions for the switch, he will probably use one of the following methods of getting around it:

(*a*) Remove the door stop strip from the frame of the doorway (Fig. 273), bore through on each side of the cross piece, and cut a recess in the inside of the frame, then fish the wires around.

(*b*) If on the second floor, and there is no partition directly

above, the wireman can use a pipe extension bit (Fig. 270, *I*), drilling one hole large enough to fish the switch loop through.

(*c*) If the cross piece is not too far above the proposed location of the switch, holes can be drilled on a slant from switch opening.

(*d*) Remove the wall paper directly over the cross piece, which can easily be done, especially in an old house where there are several thicknesses of paper, either dry or by dampening it. This can be done by cutting an X through the paper at the point over which the opening is to be made, and bending the paper back, but taking care not to bend it enough to crease it. Then cut a hole smaller than the paper removed, and bore holes or cut away the cross piece

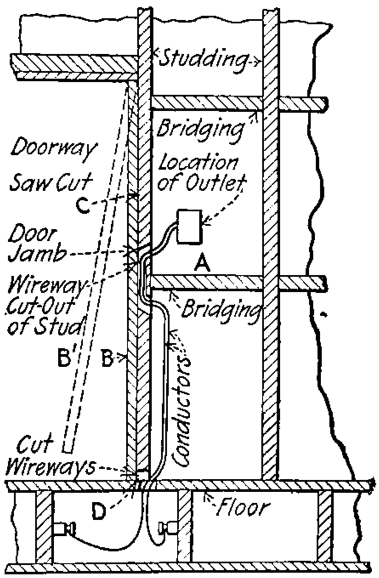


FIG. 273.—Carrying wires around a bridge.

enough so that the wires will pass. If there is a figure or flower where the cross piece is located, the same can be cut out with a sharp knife, and, after the hole is plastered up with plaster of Paris, the paper can be replaced very neatly. A careful man usually performs this operation very successfully.

(*e*) Sometimes a wireman will attempt to remove these cross pieces, when he can get at them from above, by putting a piece of pipe down between the partition, and hitting with a heavy hammer. This method is liable to cause damage to the plaster by bulging or breaking it out, and is not recommended.

(*f*) When a switch must be located on a brick wall, it is necessary to run wires in rigid or flexible steel conduit. The wall must be channeled, and the conductor buried in it, and the groove replastered. At the point where the metal terminates under the floor a suitable outlet fitting must be provided.

386. Examining Partition Interiors.—With a pocket flashlamp and a little mirror the interior of a wall or partition which would

ordinarily be inaccessible can be inspected (Fig. 274). The mirror is introduced in the outlet hole and the flashlamp and eye are held behind it as illustrated. The mirror reflects the light of the lamp onto the place to be illuminated, at the same time reflecting the image back to the eye. (William Sprunt, *Electrical World*, Mar. 2, 1912.)

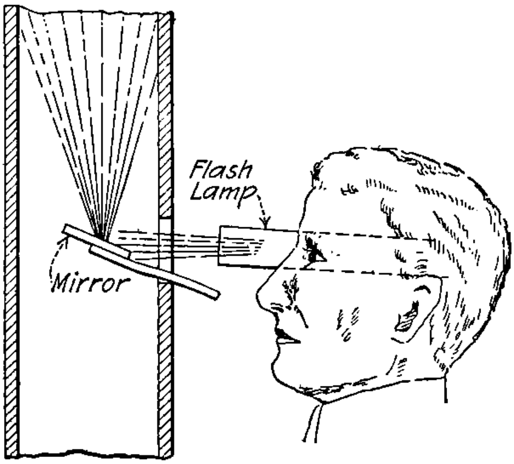


FIG. 274.—Examining partition interior.

SECTION V

TRANSFORMERS

GENERAL

1. The term stationary or static transformer (*Standard Handbook*) as ordinarily applied, refers to an apparatus for changing the voltage or current in an alternating system from one value to another with an inverse change respectively in the value of the current or voltage.

1 A. A step-up transformer is a constant potential transformer so connected that the delivered voltage is greater than the supplied voltage.

1 B. A step-down transformer is one so connected that the delivered voltage is less than the supplied; the actual transformer may be the same in one case as in the other, the terms step-up and step-down relating merely to the application of the apparatus.

1 C. A constant-potential transformer (Fig. 1) consists essentially of three parts: the primary coil which carries the alternating current from the supply lines; the core of magnetic material in which is produced an alternating magnetic flux; and the secondary coil in which is generated an e.m.f. by the change of magnetism in the core which it surrounds.

Generally the primary is the high-tension winding and it is composed of many turns of relatively fine copper wire, well insulated to withstand the voltage impressed on it. The secondary winding is composed of few turns of heavy copper wire capable of carrying considerable current at a low voltage.

2. The most important application of constant-potential transformers is for raising the voltage of an electric transmission circuit so that energy can be transmitted for considerable distances with small voltage drop and small energy loss. (See Sections I and II for a more complete discussion of this matter.)

3. The Theory of Operation of the Constant-potential Transformer.—(See Fig. 1.) It has been shown in Section I that turns of wire wound on an iron core have self-induction. When an alternating voltage is applied to such turns a current flows through them that generates a counter voltage or e.m.f. that opposes the applied voltage. From formulas, the transformer designer can compute just how many turns are necessary for a transformer of a given size so that it will generate a counter voltage equal to the applied voltage. So, in designing the primary winding of the transformer of Fig. 1, the designer would select such a number of turns for the primary winding that the counter voltage generated by it would be 2,200 volts. Hence, when the primary winding is connected to a 2,200-volt circuit, it generates a counter voltage of practically 2,200 and no appreciable current flows. A small current, the exciting current, just enough to magnetize the core, does flow but it is so small that it can be disregarded in this discussion.

Since the primary and secondary windings are on the same core, the magnetic flux generated by the magnetizing or exciting current flowing in the primary winding also cuts the turns of the secondary winding and generates in them an e.m.f. This e.m.f. will be, in accordance with a well-known law, opposite in direction to that impressed on the primary. If the secondary circuit is open no current can flow in it but if it is closed a certain current, proportional to the impedance of the secondary circuit, will flow. This current, because of the direction of the e.m.f. generated in the secondary, will be in such a direction that the magnetic flux produced in the core by it will oppose the flux due to the primary winding. It will therefore decrease the effective or resultant flux in the core by a small amount which will decrease the counter e.m.f. of the

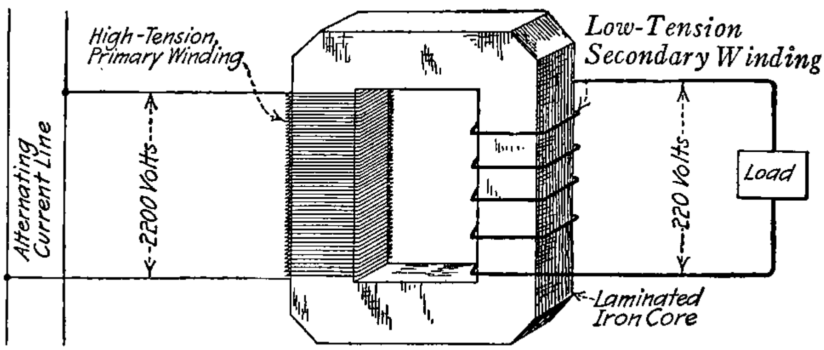


FIG. 1.—The elementary transformer.

primary winding and permit more current to flow into the primary winding. As noted elsewhere, the ratio of the number of turns in the primary winding to the number of turns in the secondary winding determines the ratio of the primary to the secondary voltage.

If the voltage impressed on the transformer is maintained constant the voltage of the secondary will be nearly constant also. When more current flows in the secondary there will be a corresponding increase in primary current. As the load on a transformer increases, the impressed voltage remaining constant, there is actually a slight drop from the no-load voltage of the secondary due to certain inherent characteristics of the transformer, but in a properly designed device this drop will be very small. Although the construction and elementary theory of the transformer are very simple, a theoretical explanation of all of the phenomena involved in its operation is very complicated. Only the principal features have been described. Some minor, though very important, considerations that would complicate things have not been treated.

4. **The ratio of the primary to the secondary turns determines the ratio of the primary to the secondary voltage.** For example, for transforming or "stepping-down" from 2,000 volts to 100 volts the ratio of the turns in the windings will be 20 to 1. The currents

in the primary and the secondary windings will be, very closely, inversely proportional to the ratio of the primary and secondary voltages because, disregarding the small losses of transformation, the power put into a transformer will equal the power delivered by it. For example, considering a transformer with windings having a ratio of 20 to 1, if its secondary winding delivers 100 amp. at 50 volts the input to its primary winding must receive almost exactly 5 amp. at 1,000 volts. The imput and output are each (practically) equal and each would equal (almost exactly) 5,000 watts.

5. The terms "high-tension winding" and "low-tension winding" are preferable to the terms "primary winding" and "secondary winding" because a high-tension winding may be the primary in one case and the secondary in another. But if the names "high-tension" and "low-tension" are used there can be no confusion.

6. The efficiency of a transformer is, as with any other device, the ratio of the output to input or, in other words, the ratio of the output to the output plus the losses. As a formula it may be expressed thus:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{Copper loss} + \text{Iron loss}}$$

7. The copper loss of a transformer is determined by the resistances of the high-tension and low-tension windings and of the leads. It is equal to sum of the watts, I^2R losses in these components at normal load.

8. Performance of Distributing Transformers.—The table shows about average values for 2,200 to 220–110-volt, 60-cycle transformers and is not particularly representative of any certain manufacturer's line.

Kva.	Watts loss		Per cent. efficiency				Per cent. regulation				Per cent. exciting current
	Iron	Copper	Full load	¾ load	½ load	¼ load	100% P.F.	90% P.F.	80% P.F.	70% P.F.	
½	15	13	94.7	94.4	93.2	88.8	2.6	2.73	2.62	2.5	8.0
1	20	24	95.8	95.7	95.0	92.0	2.4	2.51	2.41	2.25	5.5
1½	24	33	96.4	96.4	95.8	93.5	2.2	2.4	2.35	2.3	4.0
2	29	40	96.7	96.7	96.2	94.1	2.0	2.25	2.23	2.2	3.6
2½	32	51	96.8	96.9	96.5	94.7	2.05	2.42	2.45	2.4	3.3
3	33	57	97.1	97.2	96.9	95.4	1.92	2.31	2.38	2.35	3.0
4	37	70	97.4	97.5	97.4	96.0	1.81	2.55	2.75	2.85	1.9
5	43	82	97.5	97.6	97.5	96.3	1.7	2.35	2.51	2.6	1.8
7½	57	110	97.8	97.9	97.7	96.7	1.55	2.4	2.6	2.8	1.7
10	70	140	97.9	98.0	97.9	96.9	1.47	2.32	2.6	2.7	1.65
15	95	192	98.1	98.2	98.1	97.2	1.35	2.2	2.42	2.58	1.5
20	123	255	98.1	98.2	98.1	97.3	1.35	2.6	3.0	3.25	1.3
25	138	305	98.2	98.3	98.3	97.5	1.3	2.6	3.0	3.3	1.25
30	158	370	98.3	98.4	98.3	97.6	1.29	2.75	3.2	3.5	1.15
37½	175	415	98.4	98.5	98.5	97.9	1.18	2.9	3.43	3.8	1.05
50	239	520	98.5	98.6	98.5	97.8	1.14	2.7	3.22	3.57	1.0

9. **The iron loss of a transformer** is equal to the sum of the losses in the iron core. These losses consist of Eddy or Foucault current losses and hysteresis current losses. Eddy current losses are due to currents generated by the alternating flux circulating within each lamination composing the core and they are minimized by using thin laminations and by insulating adjacent laminations with paint. Hysteresis losses are due to the power required to reverse the magnetism of the iron core at each alternation and are determined by the amount and the grade of iron used for the laminations for the core.

10. **Transformer Ratings.**—Transformers are rated at their kilovolt-ampere (kva.) outputs. If the load to be supplied by a transformer is at 100 per cent. power factor the kilowatt (kw.) output will be the same as the kva. output. If the load has a lesser power factor, the kw. output will be less than the kva. output proportionally as the load power factor is less than 100 per cent.

For example: A transformer having a full load rating of 100 kva. will safely carry 100 kw., if the 100 kw. is at 100 per cent. power factor or 90 kw. at 90 per cent. power factor or 80 kw. at 80 per cent. power factor.

11. **Capacities of Transformers for Operating Motors** (*General Electric Company*).—For the larger motors the capacity of the transformers in kilovolt-amperes should equal the output of the motor in horse-power. Thus a 50-h.p. motor requires 50 kva. in transformers. Small motors should be supplied with a somewhat larger transformer capacity, especially if, as is desirable, they are expected to run most of the time near full-load, or even at slight overload. Transformers of less capacity than those noted in table 12 should not be used even when a motor is to be run at only partial load.

12. **Capacities of Transformers for Induction Motors.**

(*General Electric Company*)

Size of motor horse-power	Kilovolt-amperes per transformer		
	Two single-phase transformers	Three single-phase transformers	One three-phase transformer
1	0.6	0.6	....
2	1.5	1.0	2.0
3	2.0	1 5	3.0
5	3.0	2.0	5.0
7½	4.0	3.0	7.5
10	5.0	4.0	10.0
15	7.5	5.0	15.0
20	10.0	7.5	20.0
30	15.0	10.0	30.0
50	25.0	15.0	50.0
75	40.0	25.0	75.0
100	50.0	30.0	100.0

13. **Regulation on Inductive and Non-inductive Load** (*General Electric Company*).—While with a non-inductive load such as incan-

descent lamps the regulation of transformers is within about 3 per cent., with an inductive load, the drop in potential between no-load and full-load increases to, possibly, about 5 per cent. If the motor load is large and fluctuating, and close lamp regulation is important, it is desirable to use separate transformers for the motors.

14. **The oil used in transformers** (*Standard Handbook*) performs two important functions. It serves to insulate the various coils from each other and from the core, and it conducts the heat from the coils and core to some cooler surfaces where it is either dissipated in the surrounding air or transferred to some cooling medium. It is evident that the oil should be free from any conducting material, it should be sufficiently thin to circulate rapidly when subjected to differences of temperature at different places, and it should not be ignitable until its temperature is raised to a very high value.

Although numerous kinds of oils have been tried in transformers, at the present time mineral oil is used almost exclusively. This oil is obtained by fractional distillation of petroleum unmixed with any other substances and without subsequent chemical treatment. A good grade of transformer oil should show very little evaporation at 100 deg. Cent. and it should not give off gases at such a rate as to produce an explosive mixture with the surrounding air at a temperature below 180 deg. cent. It should not contain moisture, acid, alkali or sulphur compounds.

It has been shown by Mr. C. E. Skinner that the deteriorating effect of moisture on the insulating qualities of an oil is very marked; moisture to the extent of 0.06 per cent. reduces the dielectric strength of the oil to about 50 per cent. of the value when it is free from moisture; but there is very little further decrease in the dielectric strength with an increase in the amount of moisture in the oil.

Dry oil will stand an e.m.f. of 25,000 volts between two 0.5-in. knobs separated by 0.15 in. The presence of moisture can be detected by thrusting a red hot nail in the oil; if the oil "crackles" water is present. Moisture may be removed by raising the temperature slightly above the boiling point of water, but the time consumed (several days) is excessive. The oil is subsequently passed through a dry-sand filter to remove any traces of the lime or other foreign materials.

15. **Bell-ringing transformers** are referred to in the section on *Interior Wiring* under *Bell Wiring*.

SINGLE-PHASE CONNECTIONS

16. **Connections for standard distributing transformers** are shown in Figs. 2 and 3. Distributing transformers of medium and small capacity are almost invariably arranged, as shown, with two primary and two secondary coils. By making the necessary changes in the primary-coil connections they may be used on primary circuits of either 1,100 or 2,200 volts and their secondary windings can be so connected as to deliver 110 or 220 volts or for a 110–220-volt, three-wire circuit. For changing the connections

of the primary coils a block is provided within the transformer case. The connections of the secondary coils are made, either by splicing the secondary leads or with connectors, outside of the transformer case. Distributing transformers are also made for primary voltages of 1,040 or 2,080 and corresponding secondary voltages

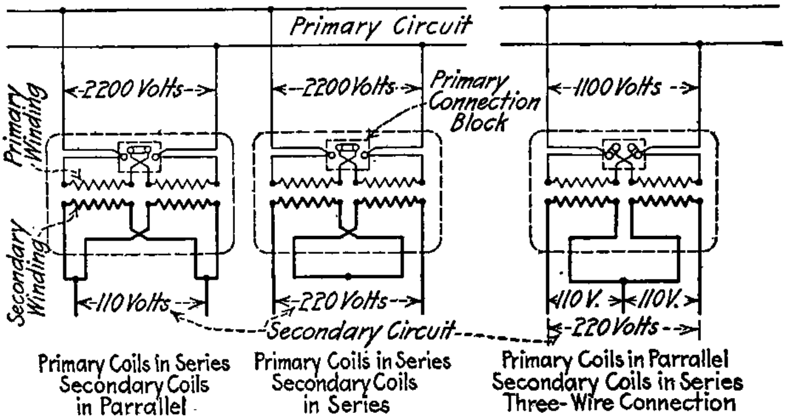


FIG. 2.—Connections of standard distributing transformers.

of 115 and 230 and have an approximate ratio of 9 or 18 to 1. Front and rear views of a Westinghouse distributing transformer are shown in Fig. 3 *A*.

17. **Transformer connections for three-wire secondary service** are shown in Figs. 2, 3 and 4. In the arrangement Figs. 2 and 3

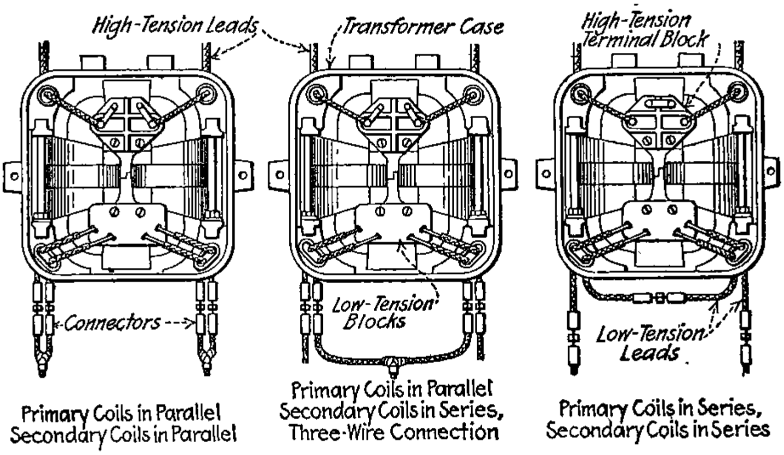


FIG. 3.—Method of interconnecting transformer secondaries with connectors.

one transformer only is used. Its secondary windings are connected in series and a tap is made to the point of connection between the two windings, providing 220 volts between the two outside wires and 110 volts on each of the side circuits. The transformer should have a capacity equal to the load to be supplied and the three-wire

circuits should be carefully balanced. If the three-wire circuits are decidedly unbalanced, the transformer should have a capacity equal to twice the load on the most heavily loaded of the two side circuits.

In Fig. 4 two transformers are shown connected to serve a three-wire circuit. The three-wire load should be balanced as nearly

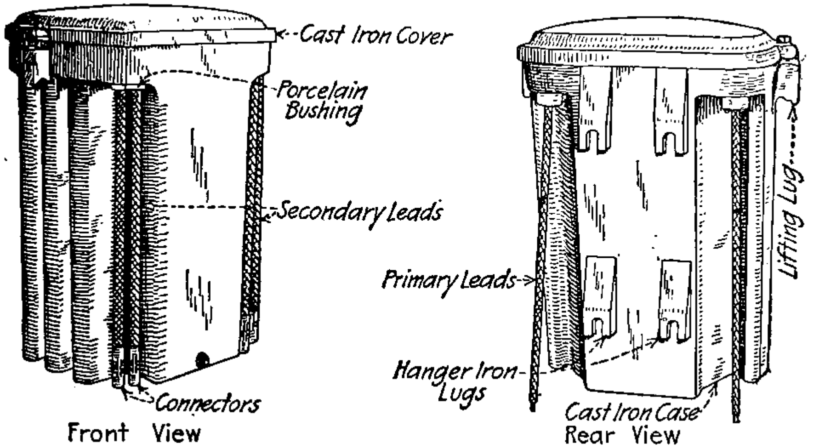


FIG. 3A.—Standard distributing transformer.

as possible and where it is very nearly balanced each transformer should have a capacity equal to one-half of the total load. If the load is badly unbalanced, each transformer should have a sufficient capacity equal to the load on its side of the circuit. See discussion of "Parallel Operation."

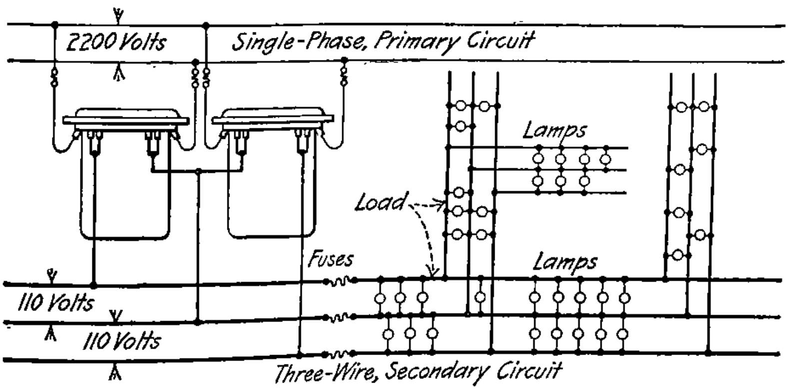


FIG. 4.—Two transformers serving a three-wire circuit.

TWO-PHASE CONNECTIONS

18. Transformers connected to four-wire, two-phase circuits are shown in Fig. 5. As a rule two-phase primary lines are four-wire as shown and to such a four-wire line the transformers are

connected to each of the side circuits as if each side circuit were a single-phase circuit not having any connection with the other. The total load should be so divided between the phases that the loads on each will be equal as nearly as possible. Each trans-

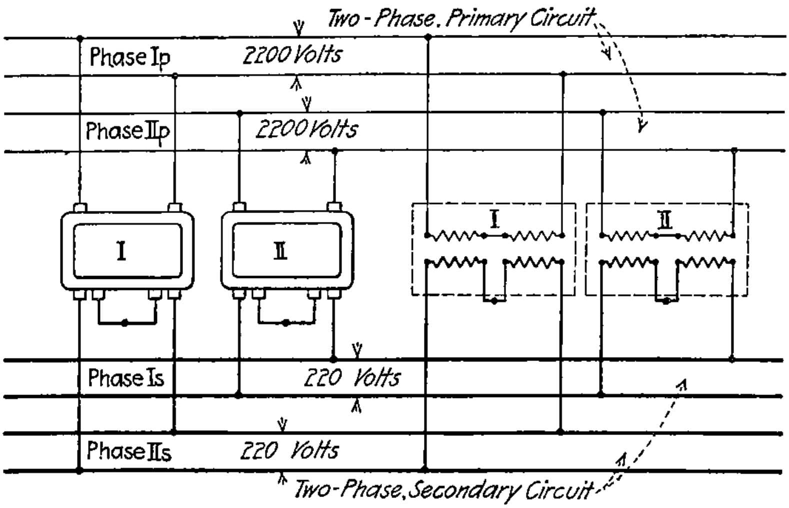


FIG. 5.—Transformers, two-phase to two-phase, four wire, connection.

former should be designed for line voltage and will carry line current. Each transformer should have a kva. capacity equal to one-half of the kva. load that is served by the two transformers.

18 A. **Transformers connected to three-wire, two-phase circuits** are shown in Fig. 5 *A*. The current in the center line wire (*AA*)

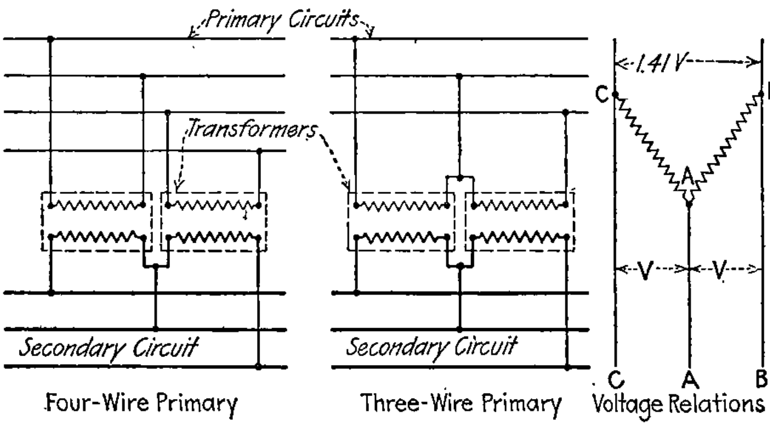


FIG. 5A.—Connections for transformers on three-wire, two-phase circuits.

is 1.41 the current in either of the outer wires. Each transformer has line voltage impressed on it and carries one-half the total load. A General Electric Co. publication comments thus: "Considerable

unbalancing of voltage at the end of a transmission line or cable is experienced with the three-wire, two-phase system due to the mutual induction between phases. Where the power factor is low, a still worse regulation is obtained, making satisfactory operation difficult. Very few systems now operate on this plan and practically all of them could be improved by the use of some other system."

19. **Mixed connections are sometimes made with two-phase transformers** as shown in Fig. 6. With improper connections such as those shown, difficulty will be experienced in the operation of motors and they may not run at all.

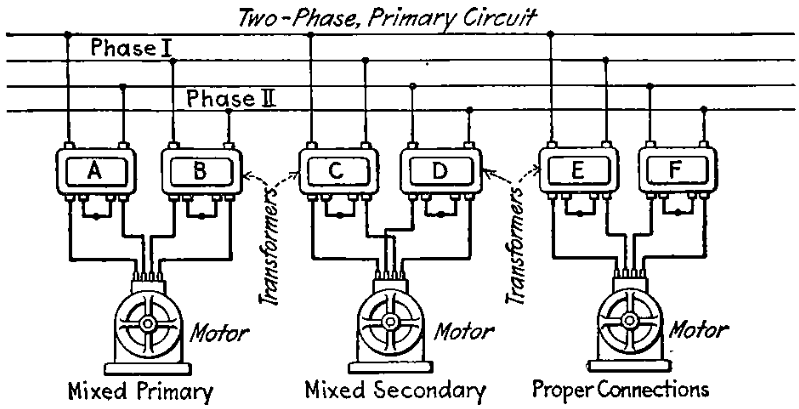


FIG. 6.—Correct and incorrect connections for transformers serving two-phase motors.

THREE-PHASE CONNECTIONS

20. **Comparison of one three-phase transformer as against a group of single-phase transformers** (*Standard Handbook*) that may be employed for obtaining the same service have been summed up by Mr. J. S. Peck as follows: Advantages of three-phase transformer: First, lower cost; second, higher efficiency; third, less floor space and less weight; fourth, simplification in outside wiring, and fifth, reduced transportation charges and reduced cost of installation. The disadvantages of the three-phase transformer are: First, greater cost of spare units; second, greater derangement of service in the event of break-down; third, greater cost of repair; fourth, reduced capacity obtainable in self-cooling units; and fifth, greater difficulties in bringing out taps for a large number of voltages. It is considered that the three-phase transformer has certain real and positive advantages over the one-phase type, while its disadvantages are chiefly those which result in the event of break-down—an abnormal condition which occurs at rarer and rarer intervals as the art of transformer design and manufacture advances.

21. **Transformers with both primary and secondary coil delta (Δ) connected** are shown in Fig. 7. All three of the transformers are connected in series in a closed circuit and each line wire is connected

to the connection between two of the transformers. The voltage imposed on either the primary or secondary of the transformer is the primary or secondary line voltage, respectively. The current in either winding = line current $\div\sqrt{3}$, or line current $\times$ 0.58.

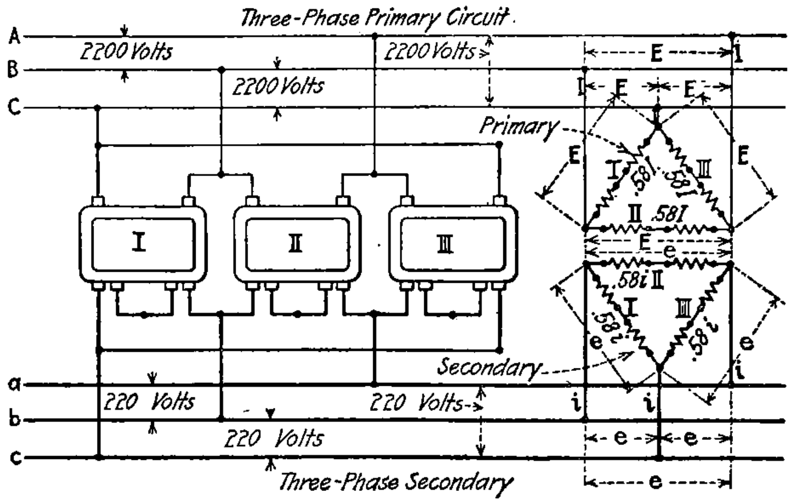


FIG. 7.—Transformers, delta-connected on both primary and secondary on three-phase circuits.

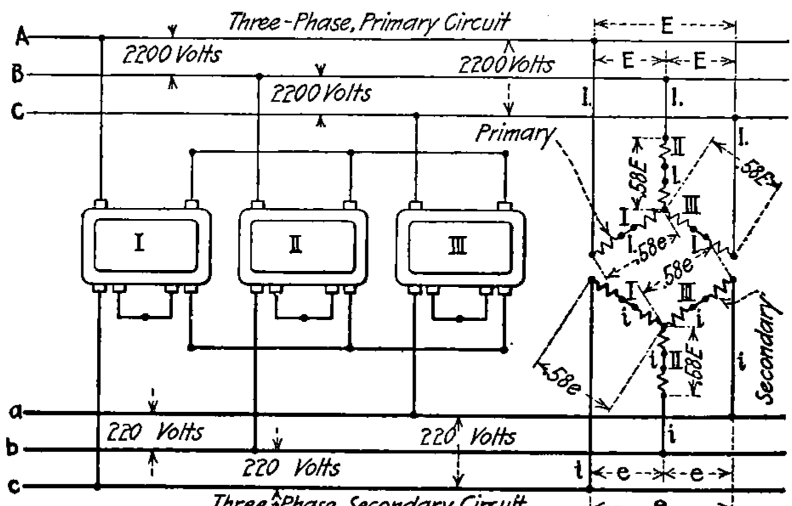


FIG. 8.—Transformers, star-connected on both primary and secondary on a three-phase circuit.

The kva. capacity of each transformer should be equal to one-third the total kva. of the load to be served. The total kva. load transmitted by a balanced three-phase line $=1.73\ IE$ (where I is

the line current in each line wire and E is the voltage between wires). Therefore, the kva. capacity of each transformer should be $1.73\ IE \div 3 = 0.58\ IE$.

22. Transformers with both primary and secondary coils, star-connected, from a three-wire primary circuit, are shown in Fig. 8. The current in each transformer winding is the same as the line current and the voltage imposed on each winding = line voltage $\div \sqrt{3} =$ line voltage $\times$ 0.58. The kva. capacity of each transformer should be equal to one-third the total kva. of the load to be served. The total kva. load transmitted by a balanced three-phase line $= 1.73\ IE$ (where I is the line current in each line wire and E is the voltage between wires). Therefore, the kva. capacity of each transformer should be $1.73\ IE \div 3 = 0.58\ IE$.

The star-star connection is seldom used.

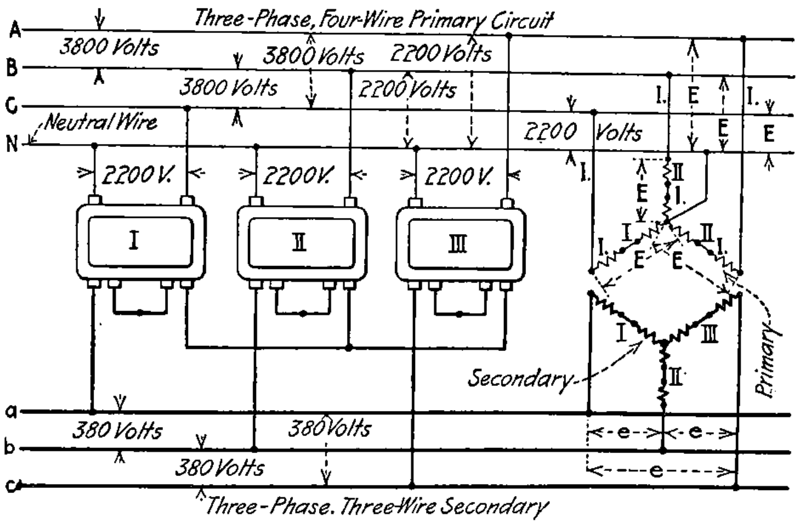


FIG. 9.—Transformers, star-connected on both primary and secondary on three-phase circuits (four-wire primary circuit).

The same grouping except that the primary circuit is four-wire is shown in Fig. 9. In thus connecting transformers from a four-wire, primary circuit it should be remembered that each right-hand primary terminal connects with a line wire and each left-hand terminal connects with the neutral wire or the reverse, respectively. The voltage and current relations are shown in the illustration.

23. Transformers delta-connected to the primary circuit and star-connected to the secondary circuit are shown in Fig. 10. Any group of transformers can be connected with either their primary or secondary coils connected in either star or delta. With the primary delta-connected and the secondary star-connected as shown, the secondary voltage will be 1.73 times what it would be if it were delta-connected. For example, in the illustration (the transformers are assumed to have a 10 : 1 ratio) with a delta secondary connection the secondary line voltage would be $2,200 \div 10 = 220$ volts, but with a star or Y secondary connection the secondary

voltage is $220 \times 1.73 = 380$ volts. It should be noted that with a delta-connected primary an increase of 15 per cent. in the primary voltage and a star secondary connection will make the secondary voltage twice what it would be with delta-connection and normal primary voltage.

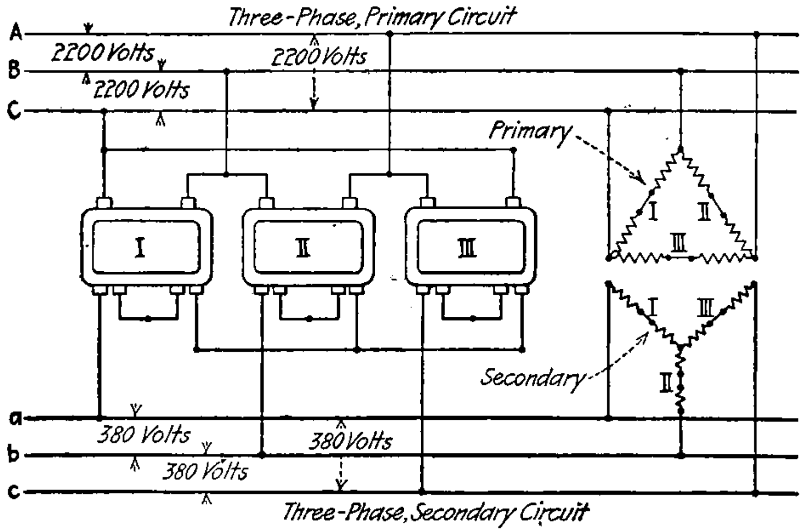


FIG. 10.—Transformers, delta-connected, primary and star-connected secondary.

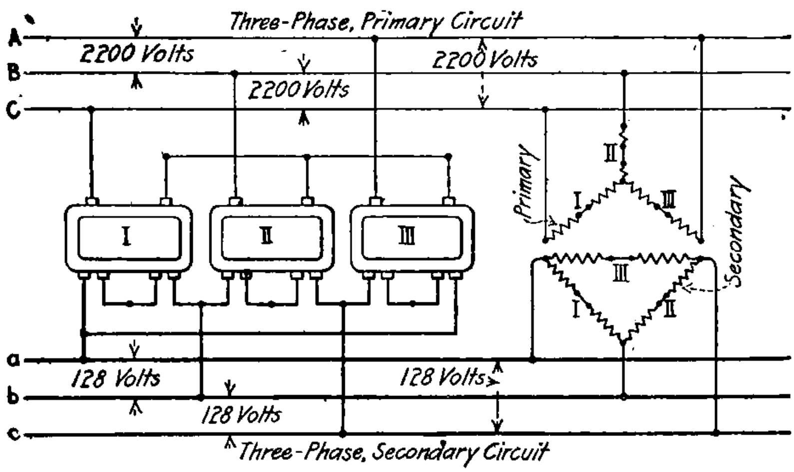


FIG. 11.—Transformers, star-connected primary and delta-connected secondary.

24. **Transformers star-connected primary and delta-connected secondary** are shown in Fig. 11. This is the reverse of the grouping described in **23** and the secondary voltage will be but 0.58 times as great as if both secondary and primary were star-connected.

25. The Three-phase V- or Open-delta Connection (Figs. 12 and 13).—Line voltage is impressed on each transformer and line current flows in each transformer coil. This method is considerably used for motors but has the objection that if one of the transformers becomes inoperative the three-phase circuit served will be fed by but one transformer and hence will be inoperative. (The *Reversed-V-connection* is indicated at the primary side in Fig. 13.)

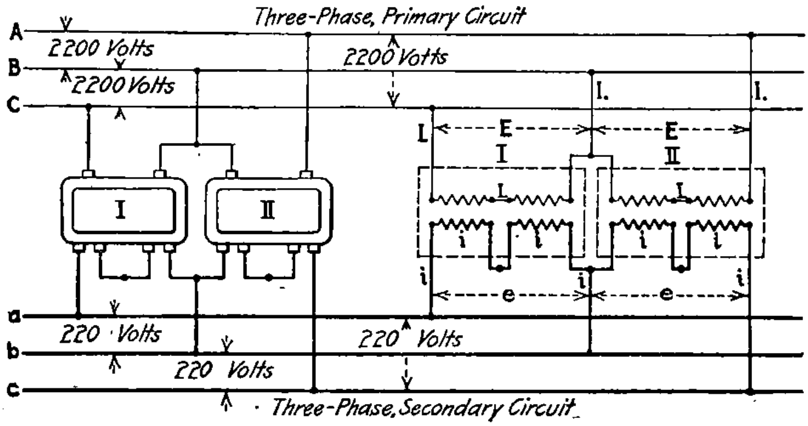


FIG. 12.—Transformers, V- or open-delta primary and secondary (three-wire, three-phase primary circuit and three-wire, three-phase secondary circuit).

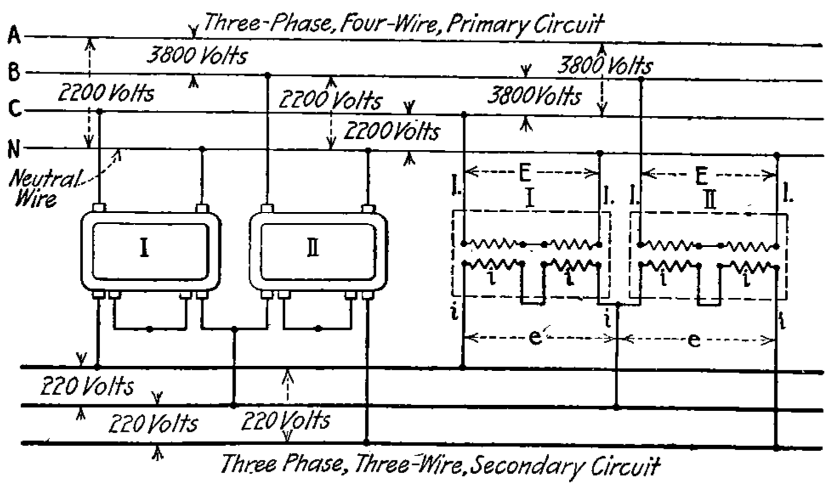


FIG. 13.—Transformers, primary connected in reversed- V and secondary V- connected (four-wire, three-phase primary circuit and three wire, three-phase secondary circuit).

The combined capacity of two transformers (*Gear and Williams*), connected by this method and serving a given load should be 15.5 per cent. greater than the combined capacity of three transformers, delta- or star-connected and serving the same load. For instance if three 5-kva. transformers (total capacity 15 kva.) are required

for a certain installation and they are replaced by two $7\frac{1}{2}$-kva. transformers (total capacity 15 kva.) the two transformers will be overloaded by 15.5 per cent. at a full load of 15 kw. at 100 per cent. power factor.

For example, assume that in a three-transformer installation the current in the secondary line is 17.3 amp. This imposes a load of 10 amp. on the transformer secondary coils. At 200 volts this is 2 kw. per transformer or 6 kw. in all. If, now, two 3-kw. transformers are put in to replace the three 2-kw. units the capacity of the secondary coils would be 15 amp. But, as above noted, with the open-delta connection the current in the secondary coil is the same as the current in the line and the 15-amp. winding must carry 17.3 amp. or 15.5 per cent. overload.

In the grouping of Fig. 12, to reverse the direction of a motor served by the group, interchange any two of the primary phase wires or reverse any two of the secondary wires.

Usually two transformers for open-delta grouping of proper aggregate capacity to serve a given load will be cheaper than three transformers for star or delta grouping to serve the same load, but this is not always the case.

26. Disadvantages of the V- or Open-delta Connection (*Standard Handbook*).—For normal operation not only must each of the V-connected transformers be larger than each of the delta-connected transformers, but the two transformers must have a combined rating 15.5 per cent. greater than the three transformers. This fact taken alone does not represent a disadvantage of the V-connection, because the two larger transformers are exactly equal in constructive material and operating efficiency to the three smaller transformers. The real objection to the V-connection for serious work resides in the tendency for the local impedance of the transformers to produce an enormous unbalance of the secondary voltages and of the primary currents. In spite of this disadvantage (which is really of little consequence in 2,200-volt primary, distribution work) many V-connected groupings are in satisfactory operation.

27. Comparison between the Delta, the Star and the Open-delta Methods of Connection (*Standard Handbook*).—The choice between the methods would be governed largely by the service requirements. When the three transformers are delta-connected one may be removed without interrupting the performance of the circuit—the two remaining transformers, in a manner, acting in series to carry the load of the missing transformer. The desire to obtain immunity from a shut-down due to the disabling of one transformer has led to the extensive use of the delta connection of transformers, especially on the low-potential delivery side. It is to be noted that in case one transformer is crippled the other two will be subjected to greatly increased losses.

Thus, if three delta-connected transformers be equally loaded until each carries 100 amp., there will be 173 amp. in each external circuit wire. If one transformer be now removed and 173 amp. continues to be supplied to each external circuit wire, each of the remaining transformers must carry 173 amp., since it is now in

series with an external circuit. Therefore, each transformer must now show three times as much copper loss as when all three transformers were active, or the total copper loss is now increased to a value of six relative to its former value of three.

A change from delta to Y in the secondary circuit alters the ratio of the transmission e.m.f. to the receiver e.m.f. from 1 to $\sqrt{3}$. On account of this fact, when the e.m.f. of the transmission circuit is so high that the successful insulation of transformer coils becomes of constructive and pecuniary importance, the three-phase line sides of the transformers are connected in "star" and the neutral is grounded. However, most of the circuits operating at 100,000 volts or more are not grounded and the transformers are joined in "delta" and insulated for the full e.m.f.

See also **26** regarding properties of an open-delta connected group.

28. Comparative Cost of Transformers for Different Groupings for Three-phase Service.—The following table shows the costs of the single-phase transformers, of proper capacities for either a delta or an open-delta grouping and of a three-phase transformer to serve a 75-kva. installation.

Method of connection or grouping	Number of transformers required	Capacity of each transformer, kva.	Aggregate capacity	Cost per transformer	Aggregate cost
Delta (Δ)	3	25	75	$213	$639
[1]Open Delta (V)	2	40	80	312	624
Three-phase transformer	1	75	75	546	546

[1] The theoretical aggregate capacity of two single-phase transformers for open-delta grouping for a 75-kva. three-phase load would be (see 25) $75 \times 1.15 = 86.3$ kva. or $86.3 \div 2 = 43.2$ kva. per transformer. The nearest commercial capacity to 43.2 kva. was 40 kva., which gives an aggregate capacity of 80 kva. which is sufficiently close to the theoretical requirement for practical work.

SPECIAL TRANSFORMER CONNECTIONS

29. Transformers connected for transforming from three-phase to two-phase or the reverse are illustrated in Fig. 14 which shows what is known as the Scott connection. The transformers required are special and each has a lead brought out from the middle point of the high-tension winding and a special voltage tap is arranged giving 86.6 per cent. of the high-tension winding. Usually two transformers just alike are purchased so that they will be interchangeable. These special transformers can be purchased from any of the large manufacturers. Those shown are Westinghouse transformers. Two standard single-phase transformers for such service should have an aggregate kva. rating $15\frac{1}{2}$ per cent. greater than their group or nominal rating.

30. T-Connected Transformers for Transforming from Three-phase to Three-phase (*Standard Handbook*).—A method of employing two transformers in three-phase transformation which

practically overcomes the disadvantages of the V-connection, and possesses considerable merit, is found in the T-connection. As indicated in Fig. 16, one transformer is connected across between two of the line wires while the other is joined between the third line wire and the middle point of the first transformer. The current in the primary coil of each transformer is the same in value as that in the primary coil of the other, and the secondary currents in the two transformers are likewise equal in value. The voltage impressed across one transformer is only 86.6 per cent. of that across the other so that if each transformer is designed especially

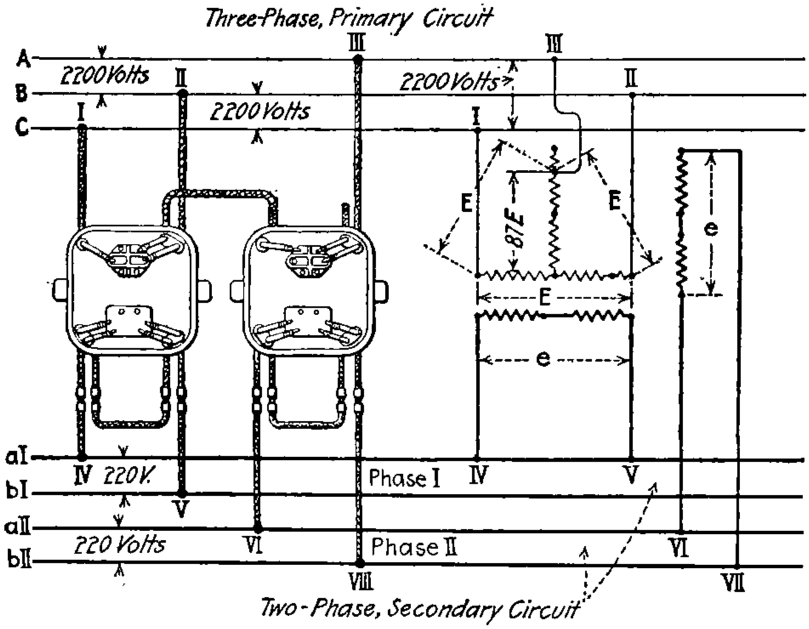


FIG. 14.—Transformers connected for three-phase to two-phase transformation.

for its work one will have a rating of *EI* and the other a rating of 0.866 *EI*, where *I* is the current in each line wire and *E* is the e.m.f. between lines. The combined rating will therefore be 1.866 as compared with 1.732 *EI* for three one-phase transformers connected either Δ or Y, or with 2,000 *EI* for two V-connected transformers.

30 A. **Requisites for Transformers for T-Connection.**—The two transformers should possess the same ratio of primary to secondary turns and a tap is brought out from the central point of one of the transformers. It is not essential that the former transformer be designed for exactly 86.6 per cent. of the voltage of the latter; the normal voltage of one can be 90 per cent. of the other, without producing detrimental results. Moreover, transformers designed for the same normal e.m.f. and intended for V-connection can be T-connected with considerable improvement in service.

30 B. **In comparing the T-connection with the Δ- or the Y-connection** (*Standard Handbook*), it is to be noted that each connection accomplishes the transformation without sensible distortion of phase relations. The T-connection allows the neutral point to be reached equally as well as does the Y-connection. The Δ-connection, however, is the only one capable of transforming in emergencies with one disabled transformer. With reference to its ability to maintain balanced phase relations, the T-connection is much better than the V-connection.

The aggregate kva. rating of two T-connected transformers should be $15\frac{1}{2}$ per cent. greater than the nominal kva. rating of the group.

31. **Explanation of the Transformation from Three Phase to Two Phase** (*Standard Handbook*).—Assume the simple case of a total value of power of 30,000 watts at 100 volts, three phase, to be transformed (without loss) to 30,000 watts 100 volts, two phase, see Fig. 15. Assuming now that the load is balanced on the two-phase side, there will be 15,000 watts per phase, or 150 amp. at 100 volts. Since the three-phase power is represented as $\sqrt{3}\,IE = 30{,}000$, where I is the current per line wire and E is the e.m.f. between line wires, I must equal 173.2 amp. because E has been taken as 100 volts.

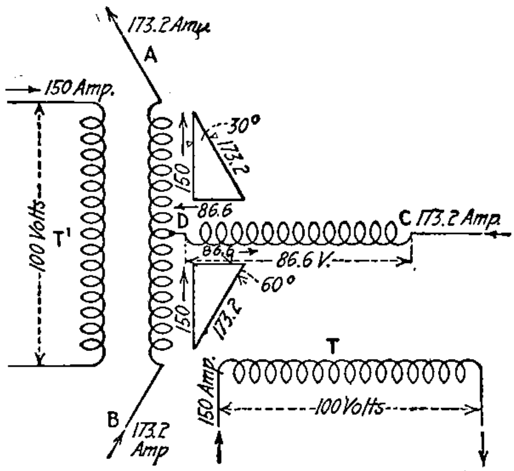


Fig. 15.—Three-phase to two-phase transformation.

As shown in Fig. 15, the three-phase coils of one transformer must be designed for 100 volts and 173.2 amp. while the three-phase coils of the other transformer must be designed for 86.6 volts and 173.2 amp. The current through the coil, CD, divides equally, a part (86.6 amp.) goes through DA and an equal part (86.6 amp.) passes differentially through DB; thus the magneto-motive force of these two currents has a resultant of zero, and it has no effect upon the core flux so far as transformer T′ is concerned. The coil, $A\ D\ B$, carries a total value of current of 173.2 amp. throughout all of its turns, but the current in one-half is 60 time-degrees out of phase with that in the other half.

That is to say the 173.2 amp. in one half is made up of a load current of 150 amp. in leading time-quadrature with which is 86.6 amp., while that in the other half is made up of a load current of 150 amp. in lagging time-quadrature with which is a superposed current of 86.6 amp. The magnetizing effect of the 173.2 amp. is, therefore, 150 amp. and the current in the two-phase side of

transformer T′ is 150 amp. In the *T*-transformer the magnetomotive force of 173.2 amp. in 86.6 per cent. turns is just equal to that of 150 amp. in 100 per cent. turns; these two currents are directly in time-phase opposition, and the apparatus operates in all respects like a one-phase transformer. The phase relations and the relative values of the several components of currents are shown in the vector diagram of Fig. 15.

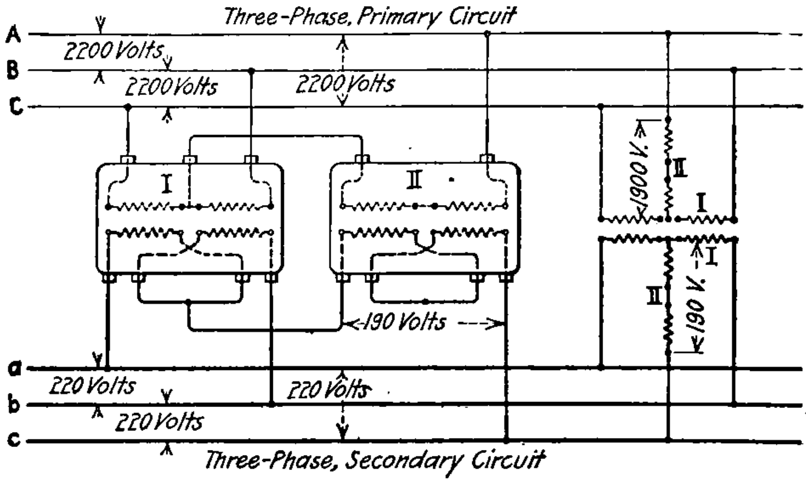


FIG. 16.—Transformers, T-connected for three-phase transformation.

32. Kilovolt Ampere Ratings of Transformers for Scott Connection (Three-phase to Two-phase) for Serving a Given Horsepower Load.—The following table gives the ratings recommended by the Westinghouse Company for transformers serving squirrel-cage induction motors and indicates the efficiency of the installation. The temperature guarantee with performances as shown is a 50 deg. Cent. rise.

Horsepower of motor	Number of transformers	Kilovolt-ampere capacity of each transformer	Total kilovolt-ampere load imposed on the group of two transformers when motor is operating at full load	Efficiency of bank of transformers with full-load on motor
½	2	½	0.75	92.8
1	2	½	1.35	94.5
2	2	1	2.40	95.2
3	2	1½	3.4	95.9
5	2	2½	5.5	96.4
7½	2	4	8.1	97.0
10	2	5	10.7	97.2
15	2	7½	15.7	97.4
20	2	10	20.9	97.6
30	2	15	31.5	97.8
40	2	20	42.0	98.0
50	2	25	51.0	98.0
75	2	37½	77.0	98.3

$$\text{Kva. on each transformer} = \frac{\text{h.p.} \times 746 \times 1.08}{(\text{eff} \times \text{P. F. of motor})}$$

$$\text{Efficiency} = \frac{\text{kva. on transformer}}{\text{kva. transformer loss} + \text{kva. on transformer}}$$

33. Booster transformers (*Electric Central Station Distributing Systems*, Gear and Williams, *Van Nostrand Co.*).—Ordinary distributing transformers applied as illustrated (Fig. 17), are used where it is necessary to raise by a fixed percentage, the voltage delivered by a line, as is necessary when transformer ratios do not give quite the right voltage or when line drop is excessive. A booster raises the voltage of any primary circuit in which it may be inserted by the amount of the secondary voltage of the booster. (See Fig. 17.)

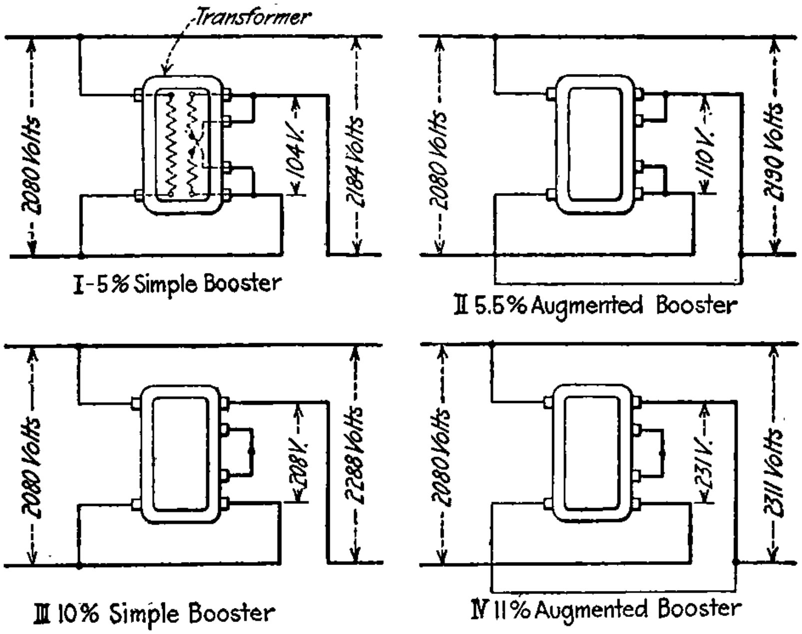


FIG. 17.—Transformers used as boosters.

Examples.—On a long, single-phase, 2,080-volt lighting branch so heavily loaded that the pressure drops more than the amount for which the normal regulation of the feeder will compensate, a 110-volt transformer inserted in the line as a booster will raise the pressure of the primary branch on the load side of the booster by 110 volts. This raises the secondary pressure 5.5 volts on all of the transformers beyond the booster.

With 440-volt service supplied by star-connected, 230-volt transformers, a 10 per cent. booster in each phase raises the normal pressure of 230–400 volts to 253–440 volts.

The connections for a simple booster are shown in Fig. 17 *I*, the line pressure being raised from 2,080 to 2,184 volts or 5 per cent. The connection at *II* is that for an augmented booster in which the line pressure is raised from 2,080 to 2,190 volts, because the primary of the booster is connected across the line on the far side and the boost r is boosted as well as the line. This gives an increase of 5.5 per cent. in the line pressure.

Fig. 17 *III*, shows a 10 per cent. simple booster and *IV* an augmented 11.1 per cent. booster.

The transformers shown in Fig. 17 have a 10 or 20 to 1 ratio and the percentages shown apply only to transformers of this ratio. If boosters having a ratio of 2,080 to 115–230 are used the percentages are increased about 10 per cent. Fig. 17 *I* would then become 5.5 per cent.; *II*, 6.05 per cent.; *III*, 11.1 per cent.; *IV*, 12.2 per cent.

34. **The proper connection of the secondary for a booster or choke transformer** must usually be determined by trial for a transformer of any given type, but once determined, any transformer of the same type may be connected in the same manner. The connections shown in Figs. 17 and 18 are correct for transformers of the principal makers.

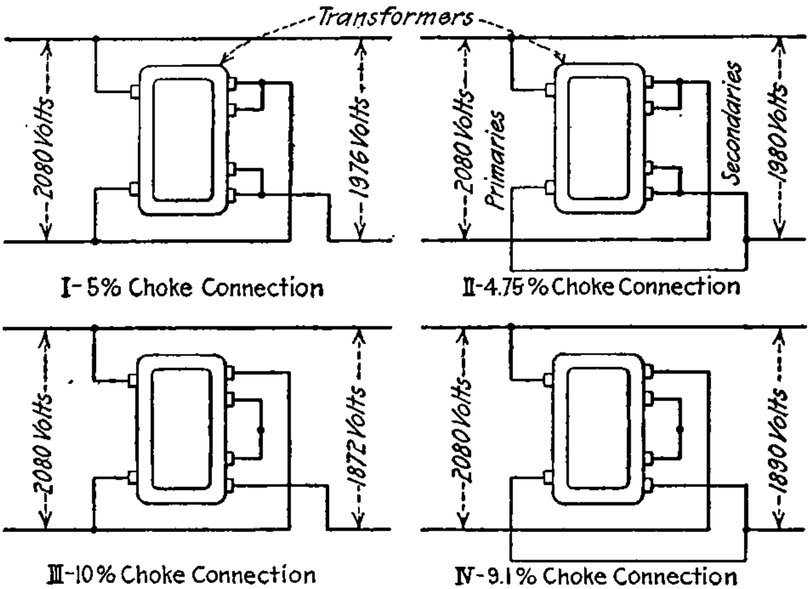


FIG. 18.—Choking transformers.

35. **Boosters are connected in a two-phase circuit** in a manner similar to that shown in Fig. 17 for a single-phase circuit. In three-wire, two-phase feeders the boosters (secondary windings) are cut into the outer wires and the primary windings are connected between the middle and the outside wires.

36. **Booster transformers in three-phase circuits are connected** as shown in Fig. 19 (*Gear and Williams, Van Nostrand Co.*).—The insertion in any phase wire of the booster voltage affects two phases. The boosting and choking effects, with transformers of various ratios, with the boosting transformers used in one, two or three phases are expressed in percentage of the primary voltage in the table of 37.

37. **Voltage Boosting and Choking Effect of Transformers Connected in Three-phase Circuits** (*Electric Central Station Distributing Systems*, Gear and Williams, *Van Nostrand Co.*).—Values in the body of the tables are the percentages that the voltages will be increased or decreased respectively by the insertion of booster or choking transformers, of different ratios, in one, two

or three, of the phase wires. Transformers are connected for boosting as shown in Fig. 19. The letters *AB*, *BC* and *CA* refer to the three phases of Fig. 19.

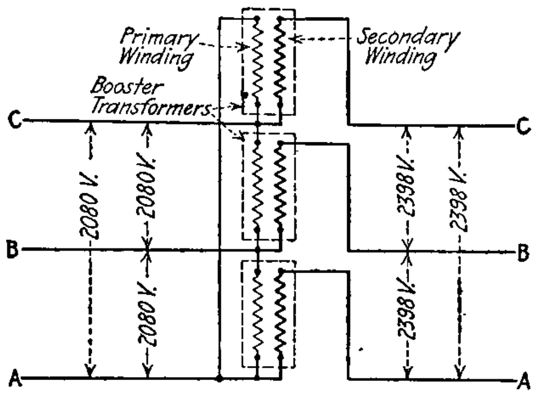


FIG. 19.—Booster transformers in a three-wire, three-phase circuit.

Boosting												
Ratios	10 to 1			20 to 1			9 to 1			18 to 1		
Booster in	AB	BC	CA	AB	BC	CA	AB	BC	CA	AB	BC	CA
A phase	10.0	10.0	5.3	5.00	0.00	2.65	11.0	0.0	5.8	5.5	0.00	2.9
A and B	15.3	10.0	5.3	7.65	7.65	2.65	16.8	5.5	5.8	8.4	2.75	2.9
A, B and C	15.3	15.3	15.3	7.65	7.65	7.65	16.8	16.8	16.8	8.4	8.40	8.4
Choking												
A phase	10.0	0.0	4.6	5.0	0.0	2.3	11.00	0.00	5.06	5.5	0.00	2.53
A and B	14.6	10.0	4.6	7.3	5.0	2.3	16.06	11.00	5.06	8.3	5.50	2.53
A, B and C	14.6	14.6	14.6	7.3	7.3	7.3	16.06	16.06	16.08	8.03	8.03	8.03

38. An arrangement of standard transformers, connected as auto-transformers, and boosters to provide 2,080 volts from a four-wire, three-phase system is shown in Fig. 20. This is taken from Gear and Williams' "*Central Station Distributing Systems*" (*Van Nostrand Co.*). The installation served was a 300-kw., 2,080-volt, three-phase motor and the source of energy was a four-wire, Y-connected system operated at about 2,160 volts between each phase wire and neutral or 3,740 between phases.

The only transformers available were six, 50 kw., units, having primary coils wound for 1,040 or 2,080 volts and secondary coils for 115 or 230 volts. By connecting these transformers for 1,040 volts on the primary and arranging two in series from each phase wire to neutral with secondaries in parallel, it was possible to tap the motor circuit off at half the line pressure. The line pressure being but 3,740, the additional voltage required to provide 4,160 volts was secured through the use of a 9 to 1 booster in each phase.

39. Choking Transformers (Gear and Williams in *Electric Central Station Distributing Systems, Van Nostrand Co.*).—When the secondary is connected in reverse order the transformer becomes a "choke," depressing the line pressure instead of raising it. This method of connection is useful where less pressure is desired.

Examples.—A 5 per cent. choke connection is shown in Fig. 18 *I*, a 4.75 per cent. choke in *II*, a 10 per cent. choke in *III* and a 9.1 per cent. choke in *IV*.

The transformers shown in Fig. 18 have a ratio of 10 or 20 to 1 and the percentages shown are only for transformers of that ratio. If choking transformers having a ratio of 2,080 to 115–230 are used, the choking percentages would be decreased to the following values: Fig. 18 *I*, 5.5 per cent.; *II*, 5.24 per cent.; *III*, 11 per cent.; and *IV*, 10 per cent.

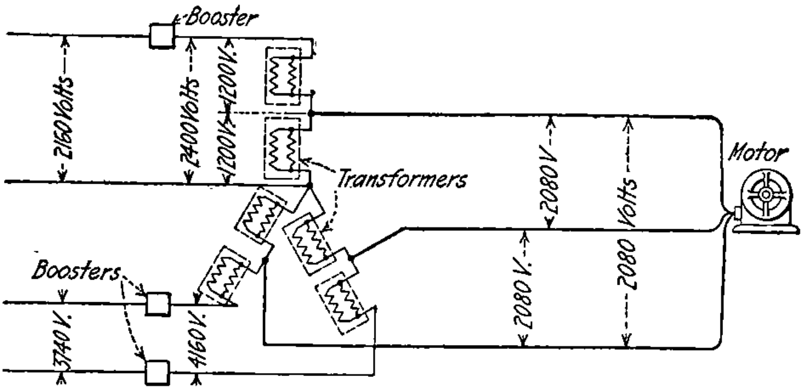


FIG. 20.—Arrangement of standard transformers, connected as auto-transformers and boosters to provide 2,080 volts from a four-wire, three-phase system.

40. There are certain precautions that should be observed in the installation of boosters (Gear and Williams, *Electric Central Station Distributing Systems*), to protect them from injury. The booster secondary is in series with the line and current is drawn through its primary windings in proportion to the load on the line. If the primary of the booster is opened while the secondary is carrying the line current the booster acts as a choke coil in the main circuit. This causes a large drop of pressure in the booster, imposing upon its secondary windings a difference of potential of two to five times normal. Under these conditions the insulation of a 2,000-volt transformer may be subjected to a pressure of 10,000 to 20,000 volts or more depending upon the load carried by the main circuit at the time.

If a fuse is used in the primary its blowing creates the above condition and the arc holds across the terminals of the fuse block until it burns itself clear. It has often been observed that where boosters have been "protected" by fuses in this way, the transformer has burned out shortly after the blowing of its primary fuses if not at the time.

41. Booster Cut-out (Gear and Williams).—In connecting or disconnecting a booster the main line should be opened before

putting it in or out. If service on the line cannot be interrupted, or if it is desired to switch the booster in or out at certain times, it may be done with a series arc cut-out as in Fig. 21. The operation of the cut-out simultaneously opens the primary and short-circuits the secondary of the booster. The switch must be of a type having a positive action so that arcing will not damage its contacts at the moment the secondary is short-circuited. The arc cut-out must have sufficient carrying capacity to carry the main-line current when the booster is shunted out and standard series arc cut-outs should not be used where the line current is likely to exceed 20 to 25 amp.

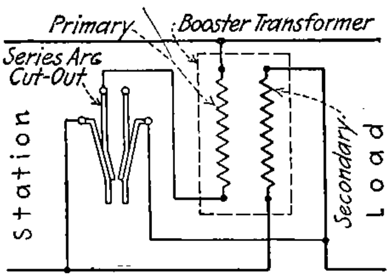


FIG. 21.—Series arc cut-out for a booster.

When the augmented booster is used the terminals of the primary winding of the transformer which goes to the cut-out should

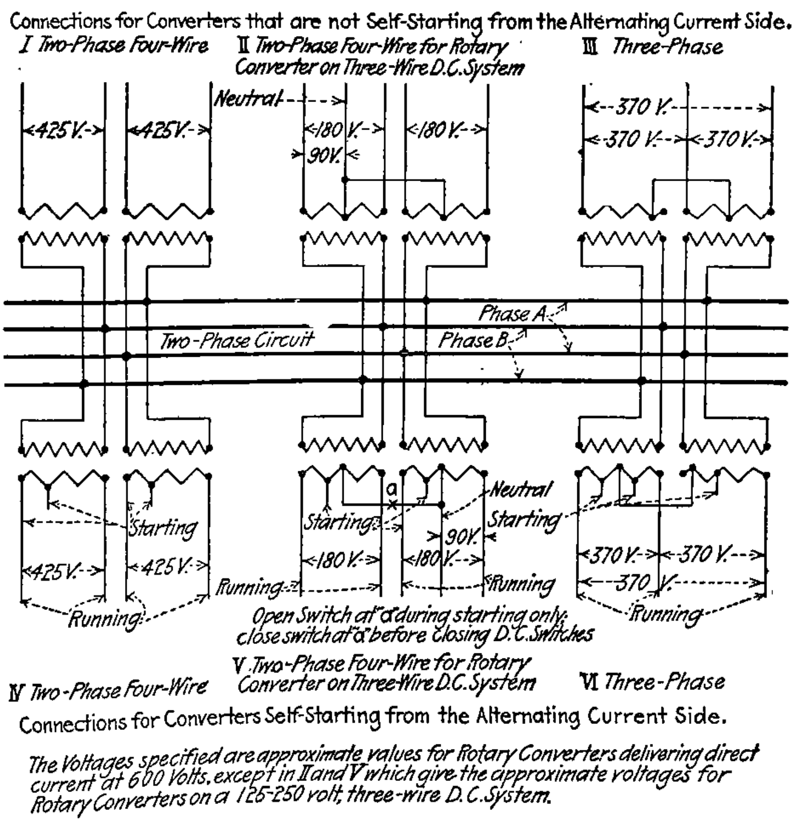


FIG. 22.—Connections for transformers serving rotary converters from a two-phase system. (*Westinghouse Electric & Manufacturing Co.*)

be connected to that terminal of the cut-out which is shown as not being in use in Fig. 21.

42. **Transformers for serving rotary converters** may be con-

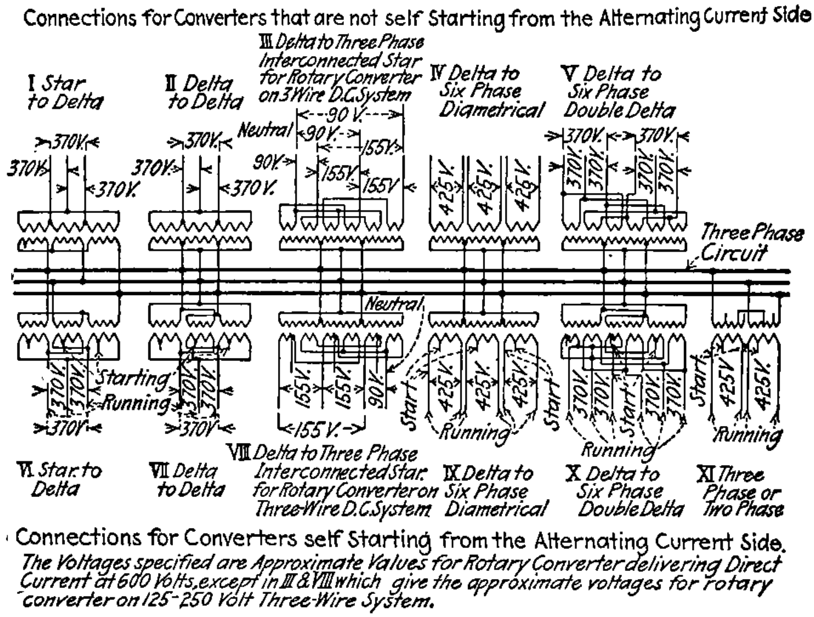


FIG. 23.—Connection for transformers serving rotary converters from a three-phase system. (*Westinghouse Electric & Manufacturing Co.*)

nected as indicated in Figs. 22 and 23 which show Westinghouse standard practice. The secondary voltages given are (with four exceptions) the ones that should be impressed on the alternating-current sides of converters so that the converters will produce a direct-current voltage of 600 for railway work. The four exceptions are noted in the illustrations.

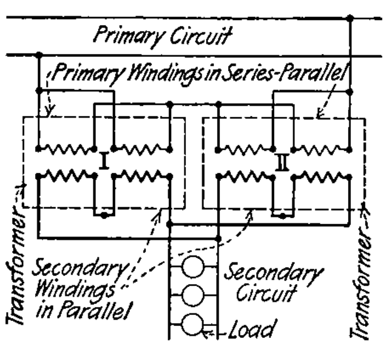


FIG. 24.—Connection for forcing parallel operation of transformers which have different impedance characteristics.

43. **A method of forcing equal division of load between transformers having considerably different impedance characteristics** (A. D. Fishel, *Distributing Transformers*) is shown in Fig. 24. Standard, 2,200-volt distributing transformers are usually provided with arrangements for the series-parallel connecting of both the high-tension and the low-tension windings and therefore the connections shown can be used. As the high-tension windings are in series the currents in the primary windings will be the same, hence the transformers will be equally loaded.

44. Transformer Connections for Obtaining 250 and 400 Volts from a 1,150-volt Line for Starting and Running a Motor (H. W. Young, *Electric Journal*).—The motor is a 20-h.p., 60-cycle machine. To supply 20 h.p. will require approximately 20 kw., which, in three transformers, corresponds to approximately three 7.5-kw. units. If these are connected to give a 5 to 1 ratio, 1,150 volts on the primary will give 230 volts for the secondary. If the transformers are connected with the high-tension windings in delta and the low-tension windings in star, as shown in Fig. 25 *I*, the ratio of the three-phase transformation will be 1,150 to 400 as desired, and by using the middle point of the low-tension windings, 200 volts will be available for starting the motor. Usually such motors will start very satisfactorily on one-half voltage.

As another solution: Two 15-kw. and two 3-kw. transformers may be connected in V with one 15-kw. and 1-kw. transformer on each leg, as shown in Fig. 25 *II*. With one of the 15-kw. transformers connected with a ratio of 2.5 to 1, 1,150 volts high tension

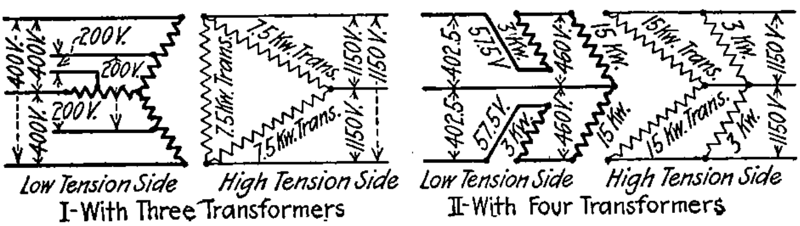


FIG. 25.—Connections for obtaining 250 and 400 volts from a 1150-volt line.

will give 460 volts low tension. The 3-kw. transformers should then be connected to give a ratio of 20 to 1, so that 1,150 volts will give 57.5 volts low tension. If the 15- and the 3-kw. transformers be connected in parallel on the high-tension side to the 1,150-volt line and in series on their low-tension windings, so that the 3-kw. transformer winding will oppose that of the 15-kw. transformer, the resultant voltage will be 460 minus 57.5 or practically 400 volts. The middle point of the 15-kw. low-tension transformer gives 230 volts, which is fairly close to that desired for starting the motor.

Note that the normal low-tension current of the 15-kw. transformer at 400 volts is 37.5 amp., and 30 amp. for the 3-kw. transformer at 100 volts, so that the current capacities of the transformers are sufficient for the three-phase load of 20 kw. at 400 volts, which correspond to approximately 29 amp. ($20{,}000 \div 1.73 \times 400$). Obviously, two 7.5-kw. or one 10-kw. transformer and one 5-kw. transformer might be substituted for the 15-kw. transformer and the 3-kw. transformer might be replaced by a 4-kw., a 5-kw., or two 1.5-kw. transformers, if any of these are available.

45. Obtaining 7.5 kw. at 500 Volts from a 60-cycle 1,000-volt Circuit with Standard Transformers (H. W. Young, *Electric Journal*).—As the high-tension voltage of the standard 1,050-volt transformer is substantially that required and the frequency nor-

mal the problem is one of determining a method for obtaining the secondary voltage of 500. The 500 volts may be secured by connecting two transformers in series (Fig. 26 *I*) the sum of the voltages of which will be that desired. If, then, a 5-kw. transformer connected as shown for 1,000 to 400 volts be used in combination with a 1.5-kw. transformer with a ratio of 1,000 to 100 the low-tension windings in series will yield 500 volts and the high-tension windings in parallel 1,000 volts as desired.

The current required on the low-tension side is 15 amp. ($500\times 15=7.5$ kw.) which is the normal current for the 1.5-kw. unit but corresponds to a 600-kw. unit with a 400-volt secondary. That is, the 5-kw. unit will be overloaded 20 per cent. This is permissible as the iron loss is considerably reduced due to the lower voltage.

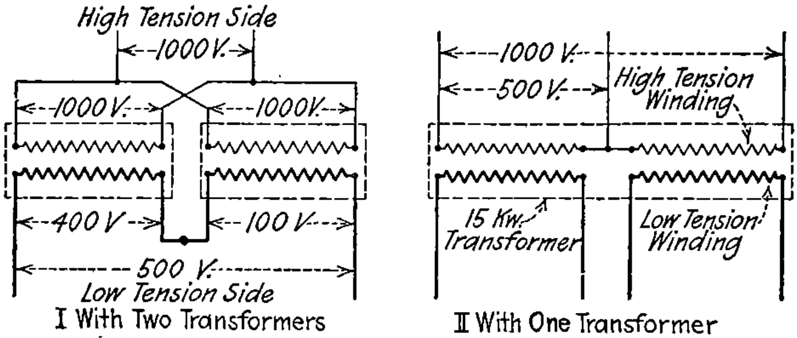


FIG. 26.—Connections for obtaining 500 volts from a 1000-volt circuit.

Instead of the 5-kw. unit, two 3-kw. units might be connected at a ratio of 1,000 to 400 with both high-tension and low-tension windings in parallel and these in turn might be connected in series on the low-tension side, with the 1.5-kw. transformer above referred to, and in parallel on the high-tension side.

Another method would be to employ a 15-kw. transformer as an auto-transformer (Fig. 27 *II*) using only the high-tension winding. In this case, 1,000 volts would be impressed over the high-tension winding when 500 volts could be taken from one-half of the winding as shown. With this arrangement the 1,000- and the 500-volt circuit are in electrical connection which may be undesirable.

46. Transforming from 360 Volts to 2,400 Volts with Standard Transformers (H. W. Young, *Electrical Journal*).—The arrangement described hereinafter (Fig. 27) was devised for the emergency supply, of a town four miles distant, from a 360-volt generator serving rotary converters. A standard transformer at 120 volts with a 20 to 1 ratio, or at 240 volts with a 10 to 1 ratio gives 2,400 volts high tension. (These voltages are considerably higher than normal although permissible in cases of emergency.) It is evident that $120+240=360$. That is, if two transformers are used with their high-tension windings in parallel for 2,400 volts and their low-tension windings in series, one connected for 240 and

the other for 120 volts, the group will operate at a ratio of 360 volts to 2,400 volts. The transformers were thus connected and energy was efficiently transmitted the four miles at 2,400 volts. Note that full-load current for the 10-kw. transformer at 240 volts corresponds to the current of the 5-kw. transformer at 120 volts, thus permitting the operation of the transformers in series on the low-tension side as indicated.

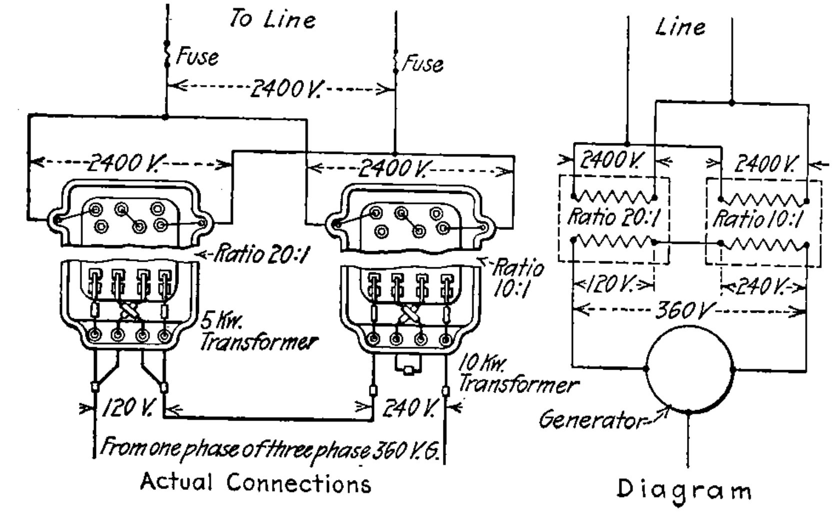


FIG. 27.—Feeding a 2,400-volt line with standard transformers from a 360-volt source.

PARALLEL OPERATION

47. Parallel Operation of Transformers.—Transformers will operate satisfactorily in parallel (Fig. 28), that is, with their

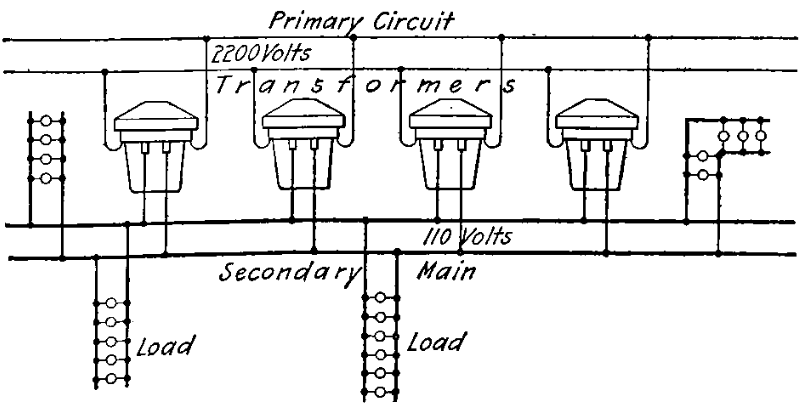


FIG. 28.—Transformers banked or operating in parallel.

high- and low-tension windings respectively connected directly to the same circuits provided—(1) they have the same ratio of transformation, (2) the same voltage ratings and (3) approximately

the same regulation. If the low-tension voltages are different the transformer having the highest voltages will circulate current to those of lower voltage and cause a continuous loss. If transformers connected in parallel do not have the same regulation they will not share the total load in proportion to their ratings. The greater share of the load will be taken by the transformer having the best regulation.

In connecting large transformers in parallel, especially when one of the windings is for a comparatively low voltage, it is necessary that the resistance of the joints and interconnecting leads does not vary materially for the different transformers or it will cause an unequal division of load.

48. With transformers of the same general voltage and capacity characteristics connected in multiple in a secondary network (*Distributing Transformers*, A. D. Fishel) little trouble will be encountered as the impedance of the line between two transformers on separate poles spaced about 100 or 200 ft. apart will normally neutralize any difference in the transformer impedances. When transformers operated in multiple are placed on the same pole the question of equal sharing of the load may be of some importance. The standard transformers of reliable manufacturers do not differ very widely in impedance characteristics however, and it is usually practicable to operate transformers of the various standard types in parallel. Often the commercial desirability of paralleling transformers of different sizes will overbalance the undesirability of some inequality in the sharing of the load which might result.

49. Polarity of Transformers.—The windings of a transformer are usually so connected to the leads extending out through the case that the direction of flow of the alternating current or the polarity of the transformer at any given instant is the same in all the corresponding leads of transformers of the same type.

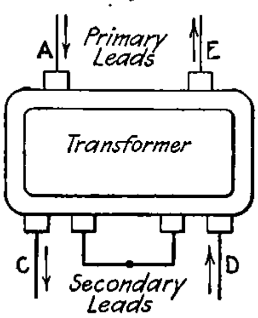


FIG. 29.—Standard instantaneous polarities.

For example: The transformer of Fig. 29 is so connected internally that at an instant when current is flowing inwardly through the primary lead *A* it flows outwardly through the secondary lead *C*. The polarities of the single-phase transformers of practically all of the large companies are as shown in Fig. 29. Where a transformer of a certain polarity is connected without transposing its leads, in parallel with one of a different polarity the effect is the same as that of a short-circuit on both units. Where such an incorrect connection has been made it can be corrected by reversing either the primary or the secondary leads.

50. The Arrangement of the Windings of a Transformer does not Necessarily Determine its Polarity.—Polarity—so called—has to do only with the plan or arrangement adopted in bringing the leads out of the case. Interchanging the positions of the leads that extend through the bushings in the case will change the polarity of the transformer.

51. Tests for Polarity of Single-phase Transformers.—Where a standard transformer of known correct polarity and of the same

ratio and voltage as the transformer to be tested is available the following simple method can be used:—Connect together (Fig. 30 *I*) the high-tension and the low-tension leads as if for parallel operation, inserting a fuse in one of the secondary leads. If both transformers are of the same polarity, no current will flow in the low-tension windings and the fuse will not blow. If the transformers are of opposite polarities the low-tension windings will short-circuit each other and the fuse will blow. The fuse should be sufficiently small that there can be no possibility of injuring the transformers.

A method of testing for polarity of single-phase transformers with a voltmeter is shown in Fig. 30, *II*. Connect the transformer as shown. Make successively voltmeter readings V, V_1, and V_2. If the transformer has standard polarity, $V+V_1$ will

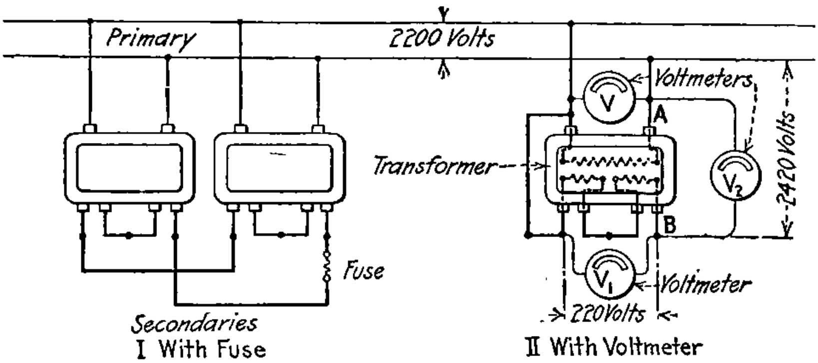


FIG. 30.—Testing transformers for polarity.

equal V_2. If the transformer is of non-standard polarity V_2 will equal $V-V_1$. For example, in Fig. 30, *II* the transformer is of standard polarity and the primary line voltage, V (2,200 volts) plus the secondary transformer voltage V_1 (220 volts) equals the voltage between A and B or 2,420 volts. With an incorrect polarity the voltmeter V_2 would read (2,200 − 220) 1,980 volts.

52. Polarity of Single-phase Transformers Connected in Banks on Three-phase Circuits (W. M. McConahey, *Electric Journal*, July, 1912).—A standard star-delta connection with six single-phase transformers is shown in Fig. 31. The polarity of *No.* 6 is the reverse of that of the other five. If the polarity of all six transformers were the same, *No.* 6 would be connected in a manner similar to that of *No.* 3 instead of having the connections of one winding reversed. If the polarity of all the transformers is the same, all banks should be connected to the line in exactly the same manner. It is possible to connect one bank differently from the others and still secure parallel operation but this is not advisable, because it is liable to lead to confusion and trouble. It is best to adopt one scheme of construction and to adhere to it.

53. Some Three-phase Transformers can be Paralleled and Some cannot (W. M. McConahey, *Electric Journal*, July, 1912).—A transformer having its coils connected in delta on both high-

tension and low-tension sides cannot be made to parallel with one connected either in delta on the high-tension and star on the low-tension or in star on the high-tension and in delta on the low-tension side. However, a transformer connected in delta on the high-tension and in star on the low-tension can be made to parallel with

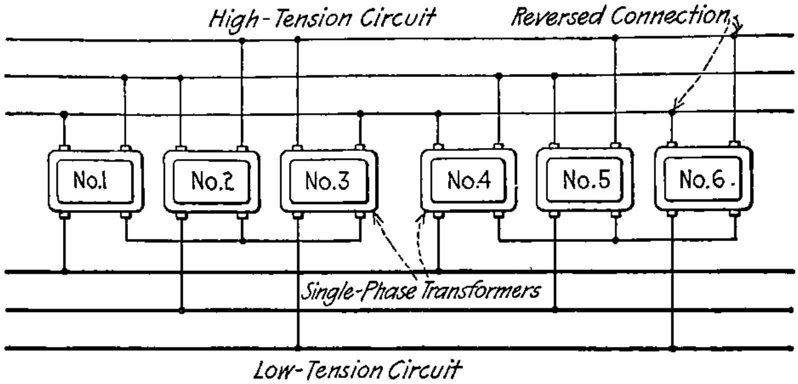


FIG. 31.—Single-phase transformers connected in a bank on a three-phase circuit.

transformers (having their coils joined in accordance with certain schemes) connected in star on the high-tension side and in delta on the low-tension side. Some three-phase transformers cannot be made to parallel (without changing the internal connection arrangement of their coils) with others using the same type of connections for the two windings. For example, a transformer connected delta to delta may have its coils so interconnected that it will not parallel with another transformer connected delta to delta. By changing the internal connections between the coils, however, it will be possible to bring out the terminals in such a way that parallel operation can be obtained.

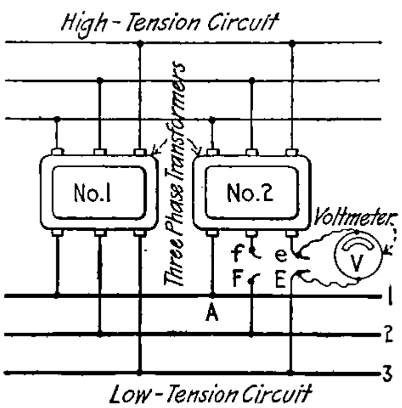


FIG. 32.—Testing three-phase transformers for parallel operation.

54. How to Determine whether or not Three-phase Transformers will Operate in Parallel.—If the transformers are available connect them as indicated in Fig. 32 leaving two leads on one of the transformers unjoined. Test with a voltmeter across the unjoined leads. If there is no-voltage between E and e or between F and f of transformer *No.* 2 the polarities of the transformers are the same and the connections can be completed and the transformers put in service.

If a voltage difference is found between E and e or between F

and *f* or between both, the polarities of the transformers are not the same. Then connect transformer lead *A* successively to mains 1, 2 and 3 and at each connection test with the voltmeter between *e* and *f* and the legs of the main to which lead *A* is not connected. If with any trial connection the voltmeter readings between *f* and *e* and either of the two legs is found to be 0 (zero) the transformer will operate with leads *f* and *e* connected to those two legs. If no system of connections can be found that will satisfy this condition the transformer will not operate in parallel without changes in its internal connections and it may be that it will not operate in parallel at all. See another paragraph on this subject.

For a very complete discussion of this subject and the description of a method whereby it can be determined by voltmeter tests whether or not two three-phase transformers which cannot be brought together for a practical test will or can be made to operate in parallel, see article in *Electric Journal* for July, 1912, by W. M. McConahey. The above material is largely abstracted from this article.

THREE-PHASE TRANSFORMERS

55. Three-phase Transformers (*Standard Handbook*).—Although there are numerous possible arrangements of the coils and cores in constructing a polyphase transformer yet it may be stated that a polyphase transformer generally consists of several one-phase transformers with separate electric circuits but having certain magnetic circuits in common. A three-phase transformer is illustrated in Fig. 33 together with the component one-phase transformer. It will be observed that a three-phase transformer requires three times as much copper as the one-phase component transformer, but less than three times as much iron. Thus in comparison with three individual transformers the three-phase unit is somewhat lighter and more efficient. Each component transformer operates as though the others were not present, the flux of one transformer combining with that of an adjacent trans-

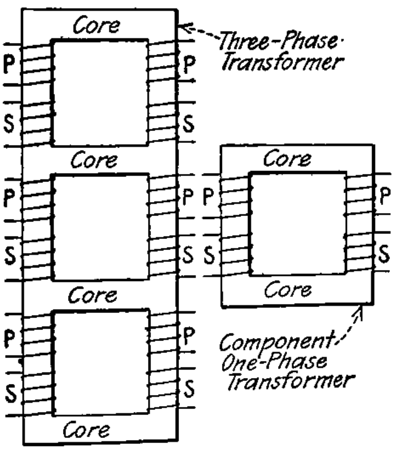


FIG. 33.—Three-phase core-type transformer.

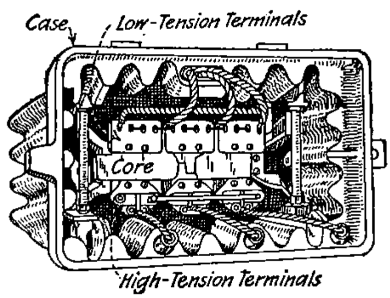


FIG. 34.—Interior view of a Westinghouse three-phase transformer.

former to produce a resultant flux exactly equal to that of each one alone. Fig. 34 shows the interior of a Westinghouse three-phase transformer.

56. Application of Three-phase Transformers (A. D. Fishel).—For central stations of medium sizes, three-phase transformers are rarely superior to single-phase except where the larger sizes can be applied in which cases the transformers are normally installed in sub-stations or central stations. The chief reason for this is the non-flexibility of a three-phase transformer. It is usually purchased for a particular size and type of load, and if that load should be changed, the transformer, representing a comparatively heavy investment, remains on the hands of the central station, whereas a single-phase transformer of one-third the size, could usually be adapted for some other service.

This feature becomes of less importance as the central station increases its size, and three-phase transformers for purely power service are now being used by a considerable number of the large central stations of this country. The three-phase transformer costs less to install and the connections are simpler, points that are of importance in connection with outdoor installations. The fact that a failure of a three-phase transformer would interrupt service more than the failure of one single-phase transformer in a bank of three, is of little importance because of the comparatively few failures of modern transformers. On the other hand, especially for 2,200 volt service, the single-phase transformer has been carried to a high degree of perfection, and is manufactured in much larger quantities, so that better performance is usual and in some cases, a lower initial cost. At present (1912) the three-phase distributing transformer is used by central stations in cities of 100,000 population or less only for special applications and not for standard power service.

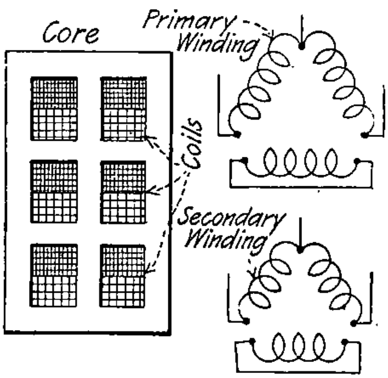


FIG. 35.—Operating a damaged three-phase transformer.

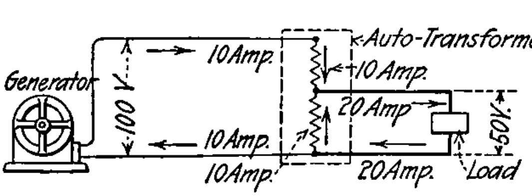
57. Methods of Connecting the Windings of Three-phase Transformers (*Standard Handbook*).—The windings of each component transformer are connected to the external circuits just as though this component were a one-phase unit; that is, the primaries may be connected either Y or delta. Moreover the relative advantages of the Y-connection and the delta-connection are quite the same with one three-phase transformer as with three one-phase transformers. The delta-connection is advantageous in some cases in that if the windings of one phase become damaged by short-circuiting, grounding or through any other defect it is possible to operate with the other phase windings V-connected.

58. In operating a damaged three-phase transformer on two coils it is necessary to separate the damaged transformer windings

electrically from the other coils, as indicated in Fig. 35. The high-potential winding of the damaged phase should be short-circuited upon itself and the corresponding low-potential winding should also be short-circuited upon itself. The winding thus short-circuited will choke down the flux passing through the portion of the core surrounded by them without producing in any portion of the winding a current greater than a small fraction of the current which would normally exist in such portion at full load.

AUTO-TRANSFORMERS OR COMPENSATORS

59. The Auto-transformer (*Standard Handbook*).—The most efficient and effective method of operating a stationary transformer (when the ratio of transformation is not too large) is as an auto-transformer; that is with certain portions of the windings used simultaneously as the primary and the secondary circuit. The electrical circuits of a one-phase auto-transformer (sometimes called a "compensator" or a "balance coil") are indicated in Fig. 36. The auto-transformer has only one coil a certain portion of which is used for both the high-tension and the low-tension winding. The number of turns of this coil is the same as would be required if it were used exclusively for the high-tension winding and a separate additional coil were used for the low-tension winding. Moreover, when the ratio of transformation is 2 to 1 or 1 to 2, the amount of copper in the one coil is exactly the same whether it is used as an auto-transformer or as a high-tension coil of a two-coil transformer of the same rating. Not only is there less copper required for an auto-transformer than for a two-coil transformer but less iron is needed to surround the copper.



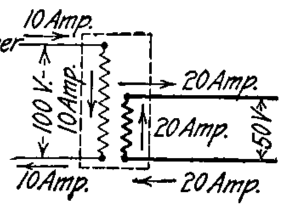


FIG. 36. FIG. 37.

FIG. 36.—Electric circuits of a 1-kw., single-phase auto-transformer.

FIG. 37.—Electric circuits of a 1-kw., single-phase, two-coil transformer equivalent to the auto-transformer of Fig. 36.

Referring again to Fig. 36 it is to be noted that the one-coil is designed for 10 amp. throughout and for a total e.m.f. of 100 volts. Evidently the voltage per turn is uniform throughout, so that to obtain 50 volts it is necessary merely to select any two points on the continuous winding such that one-half of the total number of turns is included between them. The load current of 20 amp. (required for 1,000 watts at 50 volts) is opposed by the superposed 10 amp. of primary current, so that even in this section of the coil the resultant current is only 10 amp.

If an ordinary two-coil transformer had been used, the circuits would have been as noted in Fig. 37, while the required constructive

material would have been approximately as indicated in Fig. 38 *I*. So far as concerns its constructive material, a 1-kw., 2 to 1 ratio auto-transformer is the equivalent of a 1 to 1 ratio 0.5 kw., two-coil transformer as shown in Fig. 38, *II*. The latter transformer requires about 14 lb. of copper and 28 lb. of iron as compared with about 22 lb. of copper and 34 lb. of iron for the transformer of Fig. 38, *I*. Moreover, the losses of the auto-transformer are correspondingly less than those of a two-coil transformer.

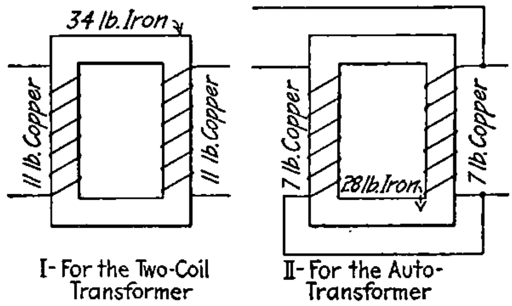


FIG. 38.—Comparison of constructive material required for a transformer and for an auto-transformer.

60. Standard Transformers used as Auto-transformers.—The applications shown in Figs. 39 and 40 are from Gear and William's *Central Station Distributing System*. The connections of Fig. 39, *I* are those for providing a 110-volt distribution on a 220-volt system. The load is assumed as 20 amp. The arrow-heads and figures indicate the distribution of current in the windings. Obviously a transformer of a wattage equal to that of the load, is

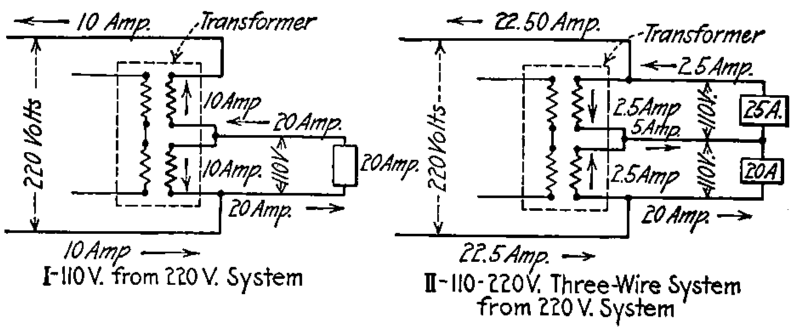


FIG. 39.—Standard transformers used as auto-transformers.

required. At *II* the connections for a 110–220-volt three-wire system are shown. The transformer winding carries only the unbalance of current in the two sides of the system. The transformer secondary winding need be only large enough to carry the largest unbalance that is likely to occur. In the methods of both *I* and *II* the transformer primaries are left open and are not used.

Figure 40 shows other arrangements. At *I* is a connection

arrangement that can be used in a 440-volt plant where 110–220-volt lighting is required. Two transformers are connected in series with their secondary windings in series and their primary windings in parallel. It is important that the primaries be in parallel as the second transformer will, if the primaries are left open, act as a choke to the lighting current. For a 110–220-volt system as shown, transformers each of capacity equal to the load are required. A similar 110-volt distribution system requires that the

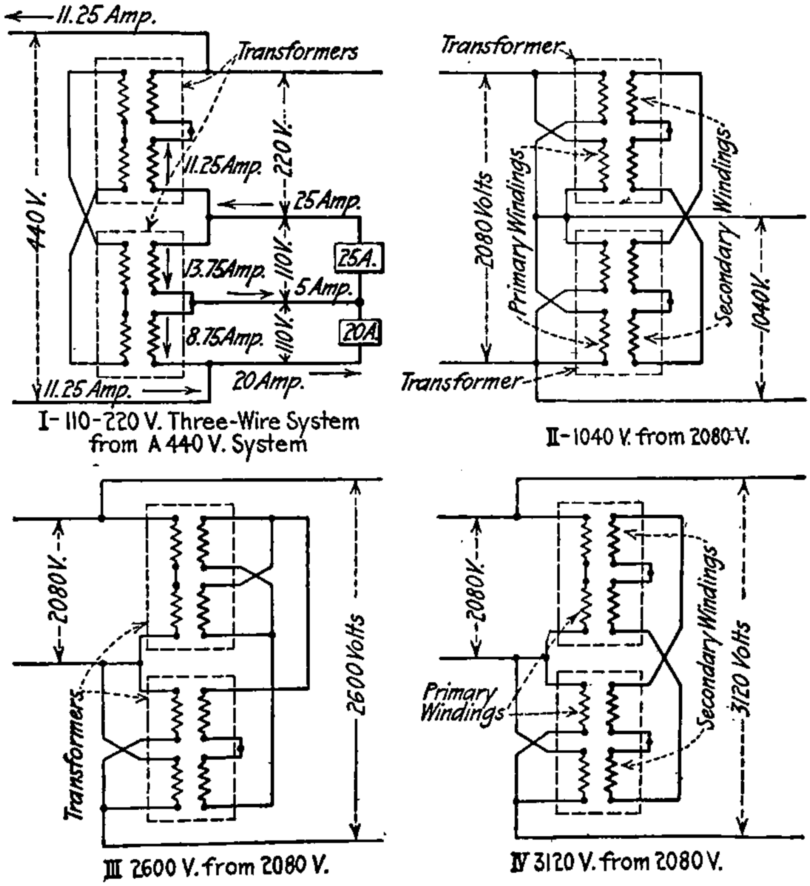


FIG. 40.—Standard transformers used as auto-transformers.

transformer on the side on which the lights are connected have a capacity of 1.5 times the load and the other one must carry half the load, making the total capacity twice the load.

Figures 40, *II*, *III* and *IV* show respectively methods whereby 1,040, 2,600 or 3,120 volts can be secured from a 2,080-volt system by the use of two transformers in series on the primary side and in multiple on the secondary side.

61. A common application of the auto-transformer is as a balance coil in a three-wire distribution from a two-wire supply

as indicated in Fig. 41, *I*. In this diagram the supply is at 200 volts, two-wire and a 2 to 1 ratio auto-transformer allows the distribution to be at 100+100 volts, three-wire. In Fig. 41, *II* the supply is at 100 volts, two-wire, while a 1 to 2 ratio auto-transformer permits distribution at 100+100 volts, three wire.

When used on a 220-volt two-wire circuit to provide a three-wire, 110-volt system, the balance coil maintains balanced voltages between the two sides of the system regardless of load conditions provided its capacity is not greatly exceeded.

62. Capacity and Ratings of Balance Coils.—The capacity of a balance coil for three-wire service is determined by the unbalanced load or the difference in load between the two circuits. For example, if there are 50 lights on one side of the coil and 100 on the other, the actual load on the coil is 50 lights. If there are 200 lights on one side and 150 on the other, the load on the coil is, as before, 50 lights; *i.e.*, the difference between the loads on the two

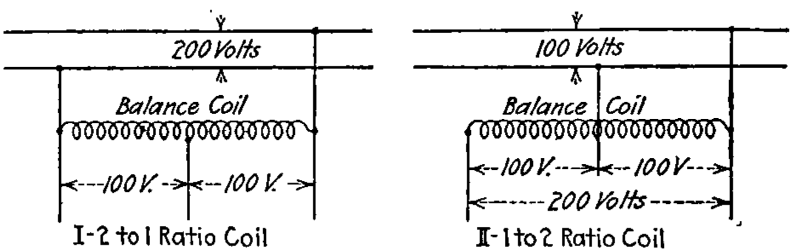


FIG. 41.—Auto-transformers used as balance coils.

circuits determines the load on the coil. Or stating it in another way: The kva. capacity of a coil represents the normal unbalancing allowable between the side circuits.

The reason for this is that only the unbalanced current flows through the coil, and on this account a balance coil may be placed on a circuit supplying any number of lights, provided that the difference between the loads on the two circuits does not exceed the capacity of the coil. In selecting a three-wire balance coil, one having a capacity sufficient for supplying one-half the total number of lights on the two circuits is sometimes chosen, so that all the lights on one circuit may be turned off without overloading the coil. This, however, is a very conservative rating and if accurate data regarding the operating conditions of the coil are obtainable, a smaller size may frequently be used. It is probably more frequent practice to consider that the unbalance will be 10 per cent. and for this condition a coil of a capacity equal to 10 per cent. of the total load on both side circuits is used. But even with the above conservative rating, the balance coil is lower in first cost, lighter in weight and much more efficient in operation than a transformer with separate primary and secondary windings. The kva. rating of a five-wire balance coil represents the maximum unbalancing allowable between any two side circuits.

The internal losses in the balance coil, both in the iron core and in the windings, are much less than in a two-coil transformer for

equivalent service. This comparison between the two-coil transformer and the balance coil holds in a general way for all classes of service, regardless of the ratio of transformation.

63. Commercial balance coils are usually oil cooled and mounted in transformer cases (Fig. 42). The coil most in demand is one for supplying a 110–220 volt three-wire circuit from a 110- or a 220-volt main. Coils for 440 to 220 volts are frequently furnished. Balance coils for supplying five-wire circuits are occasionally made. They may be for use on 440-volt circuits and have two outside and three intermediate leads, a total of five in all.

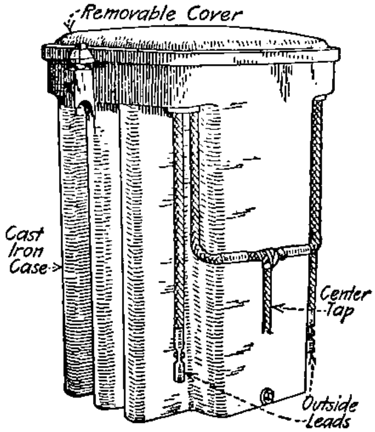


FIG. 42.—Westinghouse balance coil.

64. Another application of the auto-transformer is as a starting compensator for alternating-current motors. The compensator supplies a reduced voltage to the motor circuits while the machine is accelerating from rest. Ordinarily each auto-transformer is provided with several taps so that a number of low voltages may be obtained.

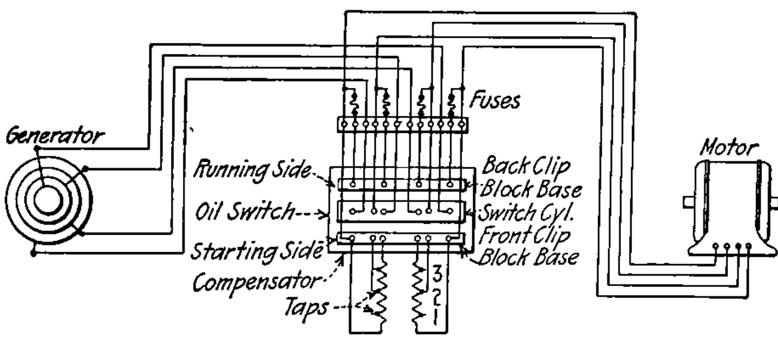


FIG. 43.—Two-phase starting compensator.

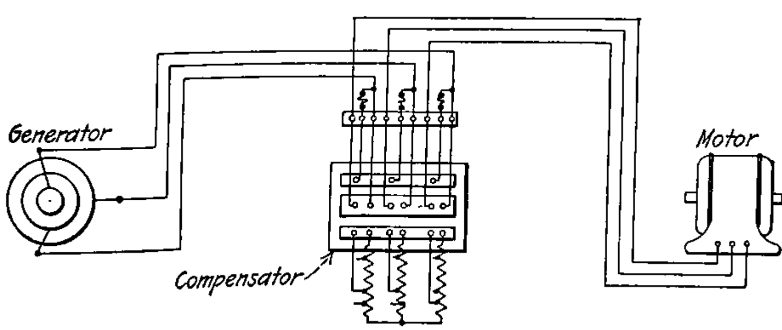


FIG. 44.—Three-phase starting compensator.

65. A starting compensator arrangement for a two-phase induction motor (*Standard Handbook*) is shown in Fig. 43. There are two auto-transformers, the two separate phase lines being connected to the ends of the separate auto-transformer windings.

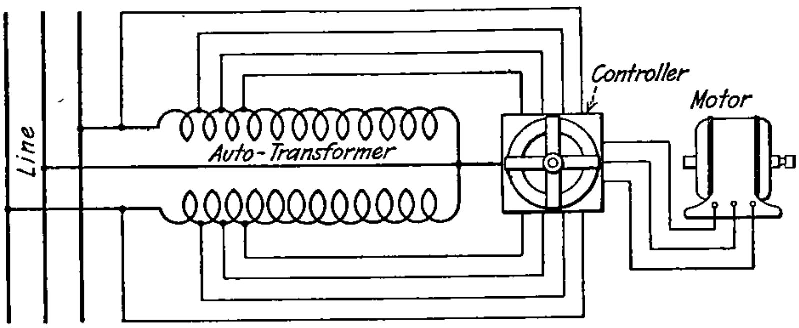


FIG. 45.—An auto-transformer, three-phase, starting compensator.

During the starting period the motor is connected between two of the ends and two intermediate taps. Fig. 44 shows a starting compensator arrangement for a three-phase induction motor. The three auto-transformer windings are Y-connected and low-voltage points are permanently selected along each leg of the Y. It is not necessary to employ three auto-transformers for starting a three-phase motor; two V-connected auto-transformers are quite satisfactory for this purpose. Fig. 45 shows two V-connected auto-transformers for starting a three-phase induction motor and operating it at four different voltages.

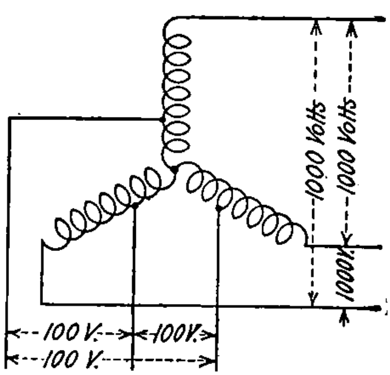


FIG. 46.—Y-connected, three-phase auto-transformer.

66. The coils of a three-phase transformer can be connected for operation as an auto-transformer, equally as well as can those of a one-phase transformer. The interconnections would ordinarily be by the Y-method although the delta-method or a combination of the Y- and delta-methods may be used. Fig. 46 represents a Y-connection for auto-transformer operation.

TRANSFORMERS OF SPECIAL FORMS

67. Transformers and Auto-transformers for Sign Lighting.—Low-voltage tungsten lamps cost less and have stronger filaments, consequently longer lives than have high voltage lamps. Hence lamps of a voltage of about 10 are widely used for signs. To produce this low voltage from ordinary 110- or 220-volt lighting

circuits, small transformers or auto-transformers, especially made for the purpose by several manufacturers, are used. The transformers are sometimes called economy coils and the auto-transformers are sometimes called compensators. The transformer is, in general, to be preferred to the auto-transformer because with the transformer the secondary circuit is insulated from the primary which removes the liability of trouble from grounds on the secondary affecting the primary and largely removes the liability of shock from the high-voltage secondary circuit. See material on sign wiring in another section.

The transformers are made of capacities of from 250 to 2,000 watts. As the normal voltage on a low-voltage sign is relatively very low it is desirable that the length of conductor between a transformer and its lamps be maintained at a minimum. This is accomplished by using several small transformers mounted at different points on a sign rather than one large one. Slate bases are required by local rules in certain cities for sign transformers and auto-transformers.

68. The current transformer (*Standard Handbook*) sometimes incorrectly referred to as a "series transformer," considered electrically, and omitting any reference to the change in its design to accomplish its specific duty, differs from the shunt or potential transformer merely in the method of use. The latter transformer is ordinarily supplied with a constant impressed voltage, the load being changed by varying the impedance (load) of the total secondary circuit, while the total impedance of the secondary circuit of the former transformer is normally held constant and the change in load is due to a simultaneous change in the primary current and e.m.f. In the shunt transformer the actual ratio of the primary to the secondary current is of minor importance while every effort is made to so design the apparatus that the ratio of the secondary power to the primary power is as nearly unity as possible. In the design of a series transformer no thought whatsoever is given to the ratio of the primary and secondary watts but attention is concentrated on the endeavor to obtain a definite ratio of secondary to primary amperes.

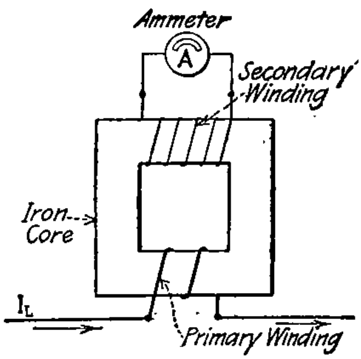


FIG. 47.—Elementary series transformer.

69. The electric and magnetic circuits of a series transformer can conveniently be represented by the diagram shown in Fig. 47, where it is used for reducing the line current to a value suitable for measurement by a low reading ammeter, which may be thoroughly insulated from the main circuit. Note that the current through the ammeter, A, is less than the line current IL by the core loss current and the exciting current, taken in proper phase relation.

70. Application of the Current Transformer.—When an alter-

nating current is so large that to connect measuring or operating instruments directly in the circuit would be impracticable, or when the voltage is so high that to do so would be unsafe, the current transformer provides a means of reproducing the effect of the primary current on a scale suited to the instrument and of insulating the instrument from the main circuit. It is a special development of the transformer principle in which a constant ratio of primary to secondary current is the important consideration instead of the usual constant ratio of primary to secondary voltage.

Current transformers are used with alternating-current ammeters, wattmeters, power-factor meters, watthour meters, compensators, protective and regulating relays, and the trip coils of circuit-breakers. It is standard practice in this country to design current transformers (regardless of their capacity or ratios of transformation) to supply a full-load secondary current of 5 amp.

For example: A 600-amp. current transfomer has a ratio of 120 : 1, that is, when a current of 600 amp. flows in the primary circuit 600 ÷ 120 = 5 amp. will flow in the secondary circuit.

Measuring instruments for use with these transformers are so designed and are provided with scales such that they give a full scale deflection when 5 amp. flows through them and normally relays trip on a 5-amp. secondary current. One current transformer will supply three or four instruments with operating current without appreciably affecting accuracy.

71. It is Unsafe to Open the Secondary Circuit of a Current Transformer when there is any Current in the Primary.—When the secondary circuit is closed the current in this circuit creates a magnetomotive force which is in opposition to the magnetomotive force of the primary current and the core flux is thereby limited to the value necessary to generate in the secondary coil an e.m.f. sufficient to produce therein a current only slightly less than the primary current in magnetizing effect. When the secondary is open there is no opposing magnetomotive force for limiting the core flux which may reach a high value. Thus even a small value of primary current produces an excessive value of core flux and a correspondingly large secondary e.m.f. The secondary voltage under these conditions reaches a value which may both damage the insulation and prove dangerous to life. Absolutely no harm can come from short-circuiting the secondary terminals of the series transformer, and this method is used when it is necessary to insert or disconnect instruments in the secondary circuit.

72. The Constant-current Transformer (*Standard Handbook*).—The operation of low-voltage arc or incandescent lamps in parallel on a constant potential system necessitates a prohibitive expenditure for conducting material when the area to be lighted is extensive and the lamps are widely separated. For such service it is the common practice to operate the lamps which are connected in series with a constant current. The constant-current transformer is a special form of apparatus which converts alternating current at a constant potential of any value to a constant (alternating) current with a voltage varying with the load. It consists of a primary coil upon which the constant voltage is impressed, a secondary coil (or

coils) movable with respect to the primary, and a core of low magnetic reluctance. It depends for its regulation upon the magnetic leakage between the primary and secondary coils.

Consider first the primary coil; with constant e.m.f. impressed upon this coil the total magnetism within the coil will be practically constant under all conditions. The e.m.f. generated in the secondary will depend upon the strength of the field which it surrounds. In all types of stationary transformers the secondary current is opposite in general time-direction to the primary, so that not only is there a repulsive thrust between the two coils but there exists a considerable tendency for the magnetic lines from the primary to be forced out into space without penetrating the secondary. In the ordinary constant potential transformer the repelling action between the two currents is prevented from producing motion of the coils by the rigid mechanical construction, while the proximity of the primary and secondary coils limits the magnetic leakage.

In the constant-current transformer, however, the repelling action is utilized to adjust the relative positions of the primary and secondary coils; when the coils are widely separated the paths for the leakage lines are increased and the lines which the secondary surrounds are fewer than when the coils are quite near together. The counter weights mechanically attached to the movable coil (or coils) are so arranged that when the desired current exists in the secondary coil (independent of its position along the core) the weights are just balanced. An increase in the current increases the repulsion and causes the coils to separate. With any current less than normal, the repelling force diminishes and the primary and secondary coils approach each other thereby restoring the current to normal. The primary can be wound for any reasonable potential (say as high as 10,000 volts) while the secondary can be wound for the voltage required for operating the arc lamps—from 15 to 200 or more lamps.

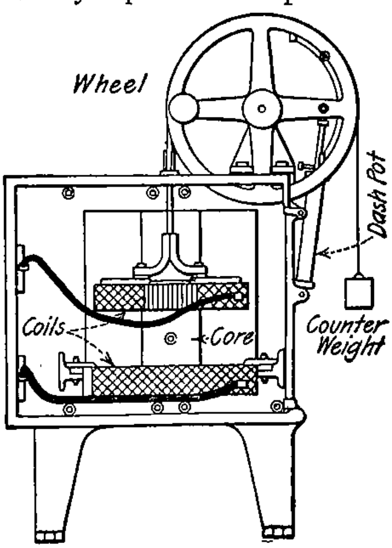


FIG. 48.—Constant-current transformer.

73. Mechanical Construction of the Constant-current Transformer.—The magnetic circuit of a constant-current transformer is usually of the "shell" type, the three limbs being placed vertically. In small sizes (Fig. 48) one of the coils is arranged in a fixed position while the other is movable. In some of the larger sizes there are two fixed primary coils and two movable secondary coils, while in others both the primary and secondary coils are movable. In any event the gravitational action on the movable coil or the gravitational action of one movable coil against another to which it is mechan-

ically interconnected, is counter-balanced accurately with an excess or deficiency just equal to the repulsive thrust of the primary and secondary coils at the desired load current. By the use of cam mechanisms for the counter-weights, or of eccentrically placed extra weights, the excess force of the counter-weights may be arranged to be equal to the variable repulsive thrust corresponding to a constant value of current in the coils at all positions of the movable coils. In fact, the transformer may be adjusted to regulate for a current of constant value at all loads or for one which either increases or decreases with increase of loads, while both the real value of the load current and its rate of change with the variation in load may be adjusted at will. In order to prevent any "hunting" action of the movable coils each transformer is sometimes equipped with a dash-pot. (See Fig. 48.)

74. Commercial constant-current transformers are built for natural air cooling or for immersion in oil. Oil has proved an excellent medium for insulation, cooling and lubrication. This type of transformer is extensively used for series street-lighting service with either arc or incandescent lamps. It is frequently employed in connection with mercury-vapor rectifiers for operating series-connected direct-current lamps. The efficiency of a constant-current transformer is high, being about 96 per cent. at full-load for a 100-lamp transformer. The power factor which depends upon the magnetic leakage, is low at all loads; it reaches about 80 per cent. at full-load and decreases therefrom in almost direct proportion to the decrease in load.

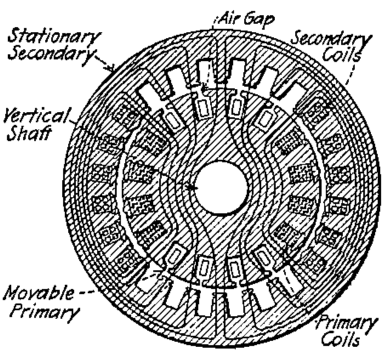


FIG. 49.—Section through a single-phase, induction-type, potential regulator.

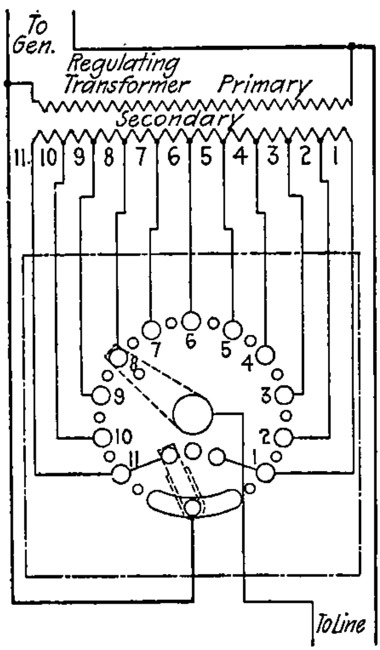


FIG. 50.—Single-phase, step-by-step type potential regulator.

75. The induction regulator (Fig. 49) is a special type of transformer, built like an induction motor with a coil-wound secondary.

which is used for varying the voltage delivered to a synchronous converter or alternating-current feeder system. In comparison with a variable-ratio transformer it possesses the advantage of being operated without opening the circuit and without short-circuiting any transformer coil. The primary of the induction regulator is subjected to the constant voltage of the supply system, the delivered voltage obtained from the secondary winding being varied by rotating the primary structure through a certain number of degrees with reference to the secondary structure. The primary structure is normally stationary, although it is movable either automatically or by hand for the purpose of varying the secondary voltage.

76. The step-by-step potential regulator is merely a stationary transformer provided with a large number of secondary taps and equipped with a switching mechanism for joining any desired pair of these taps to the delivery circuit according to the e.m.f. required. A diagram of the circuits of a regulator of this type is shown in Fig. 50. In comparison with the induction type of regulator the step-by-step type is less noisy in operation, requires less magnetizing current and is more rapid in action. However, it provides only a limited number of voltage steps and may give trouble from arcing at the switch contacts.

INSTALLATION OF TRANSFORMERS

77. Brief of Underwriters' Rules Covering the Installation of Transformers (*Factory Mutual Fire Insurance Companies' Wiring Rules*).—Where transformers are to be connected to high-voltage circuits, the local Inspection Department should always be consulted before work is begun or the apparatus is purchased, as it is necessary in many cases for best protection to life and property, that the secondary system be permanently grounded, and this cannot be done unless provision is made for it when the transformers are built.

Transformers should always be located outside of buildings, unless special permission is given to put them inside. In general, it is dangerous to locate transformers with oil-filled cases inside, as it is entirely possible for a break-down of insulation to ignite the oil, which may result in a very stubborn fire. For the same reason, the placing of these transformers on roofs is also objectionable.

Even transformers which are not oil cooled may contain a considerable amount of combustible material which, if ignited, would make a hot fire, especially if the cases are ventilated as is customary with these types of transformers. Moreover a burn-out in the windings may cause dense smoke, which might easily be mistaken for a fire and cause fire streams to be thrown into the building, with a resultant water damage. They can, therefore, be permitted inside of buildings only after the circumstances have been carefully considered and the necessary safeguards provided.

78. Size and Capacity of Transformer Fuse Wire

(Westinghouse Electric & Manufacturing Co.)

Capacity amperes	18 per cent. German silver wire	Capacity amperes	Aluminum wire
½ to ¾	No. 36	4 to 10	No. 24
¾ to 1	No. 30	5 to 10	No. 24
1 to 1¼	No. 30	10 to 15	No. 23
1¼ to 1½	No. 30	15 to 20	No. 22
1½ to 1¾	No. 30	20 to 25	No. 21
1¾ to 2¼	No. 26	25 to 30	No. 20
2¼ to 2¾	No. 26	30 to 50	No. 19
2¾ to 4	No. 26	....	....

79. Sizes of Primary Fuses Recommended for Transformers of Different Ratings

(General Electric Company)

Transformers kva. capacity	Primary volts	
	1,100–1,200 Amperes rating	2,200–2,400 Amperes rating
0.6	1	1
1.0	1	1
1.5	2	1
2.0	2	1
2.5	3	2
3.0	3	2
4.0	5	2
5.0	5	3
7.5	10	5
10.0	10	5
15.0	15	10
20.0	20	10
25.0	25	15
30.0	30	15
40.0	40	20
50.0	50	25

80. Mounting Distributing Transformers.—Units of the smaller capacities are supported on poles on cross-arms in accordance with instructions furnished by their manufacturers. Gear and Williams recommend that, for transformers of capacities larger than 20 kw., double-cross arms should be used at the top as the top arms carry most of the weight. "Where the installation consists of three 15-kw. or larger transformers it is advisable to use a larger-sized cross-arm than the standard. An arm having a cross-section of 4 in. by 5½ in. has been found ample for installations aggregating 90 to 100 kw."

"Where a large amount of power is needed which requires a number of 50-kw. units which cannot be conveniently installed inside of the building, they can be safely and conveniently installed on a platform between two or more poles as shown in Fig. 51. The use of units larger than 50 kw. is usually not advisable as they

are so heavy as to be inconvenient to handle and replacing them in case of a burn-out is a considerable task. A platform for supporting three 50-kw. units can be built by bolting in gains, between two poles, 2-3 in. × 10-in. planks and nailing to them a floor of 2-in. plank."

81. Methods of Hanging Transformers.—The methods of mounting transformers described and illustrated in the following paragraphs were taken from the *Report of the Committee on Overhead Line Construction* of the Pennsylvania Electric Association, Sept. 3, 1912. H. N. Müller of the Alleghany County Light Company of

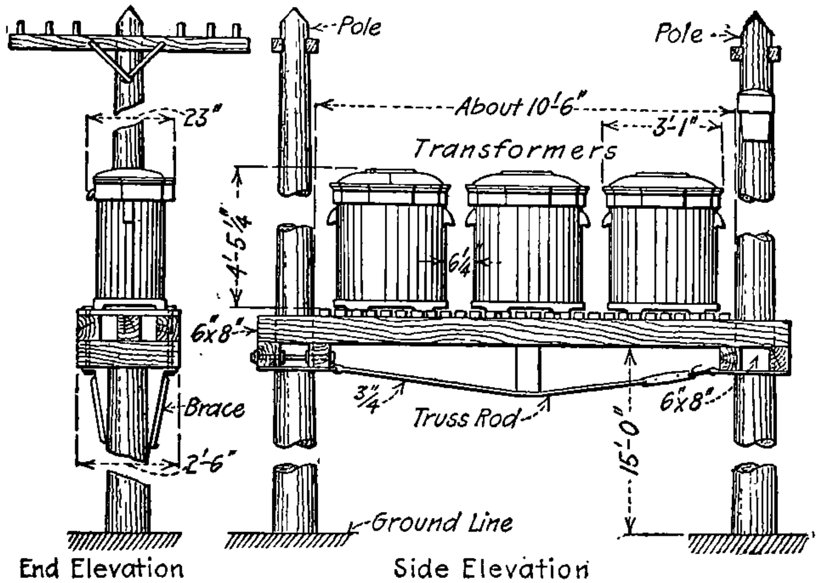


FIG. 51.—Platform for large transformers.

Pittsburgh was chairman of the committee and the practices outlined are those followed by the Alleghany Company. The methods provide ample clearances for linemen climbing the poles and assure that the wiring will remain in place and not give trouble from short circuits. Platforms are recommended for supporting the larger transformers because of the accessibility for repairs or replacements that they provide.

82. Method of Mounting Single Transformers of from 1- to 4-Kva. Capacity.—The transformer should be supported by the iron hangers furnished by the manufacturer and hung at the central point on the cross-arm and not out on the arm away from the pole. At the bottom of the hanger a section of an arm, not longer than the diameter of the pole, should be fastened to the pole with two lag bolts. The transformer can be hung on the bottom arm, if one is in place and supports lines, provided this arm is in the second gain or a lower one. The primary mains feeding the transformer should be on an upper arm.

In installations where the transformers are more than 4 ft.

below the arm supporting the primary mains, it is advisable to mount Western Union pins horizontally in the linearms. On these pins the primary wires can be tied to maintain them rigid. Iron pins should also be mounted in the transformer arm to take the stress imposed on the primary conductors by the fuse terminal screws.

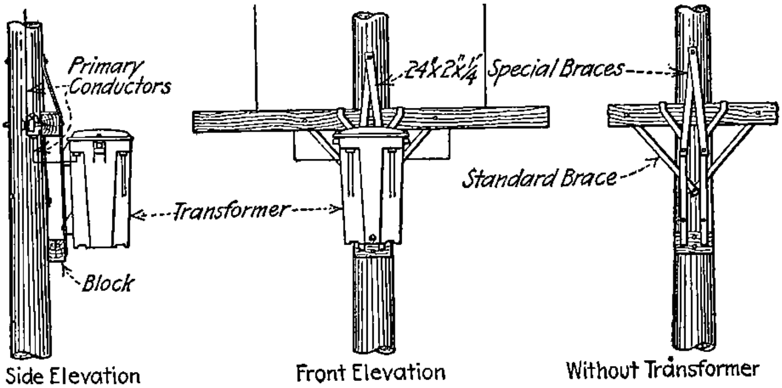


FIG. 52.—Method of supporting a 5- to 10-kw. transformer.

83. Method of Mounting Transformers of from 5- to 30-kva. Capacity. (Fig. 52.)—The same rules should be followed as outlined in the preceding paragraph with the following additions: The transformers, on account of their increased weight and dimensions, should not be hung on a linearm. A specially placed arm should be used underneath existing arms and other apparatus.

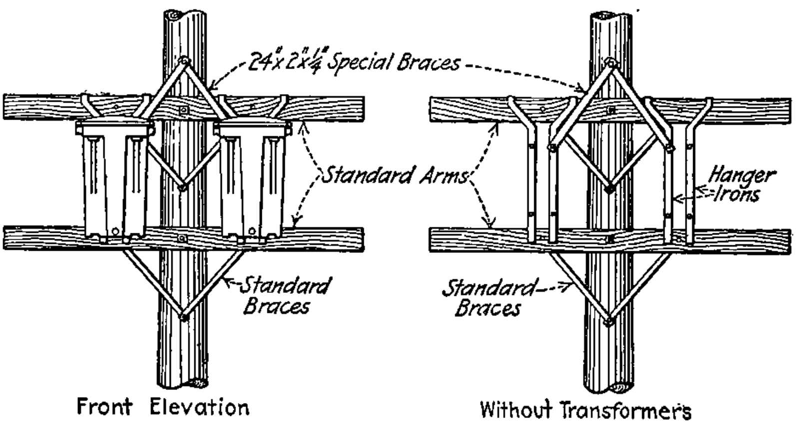


FIG. 53.—Method of supporting two 5-kva. or two 10-kva. transformers.

In addition to using the regular hangers which accompany transformers, a pair of iron braces $24 \times 2 \times \frac{1}{4}$ in. should be placed between the transformer lugs and the hanger with the hanger bolts passing through one of the holes in the braces. These braces are to be run in an upward direction and fastened to the pole with a standard through bolt. (See Fig. 52.) If the arm weakens or entirely rots

away, these two braces are of sufficient strength to support the transformer and permit cross-arm replacement.

84. Method of Mounting Two 5-kva. or Two 10-kva. Transformers. (Fig. 53.)—Construction similar to that above described should be used except that a standard arm should be placed at the bottom on which the hanger irons can rest. Also only one special brace (24×2×¼ in.) per transformer, should be placed between the lug and hanger iron next to the pole.

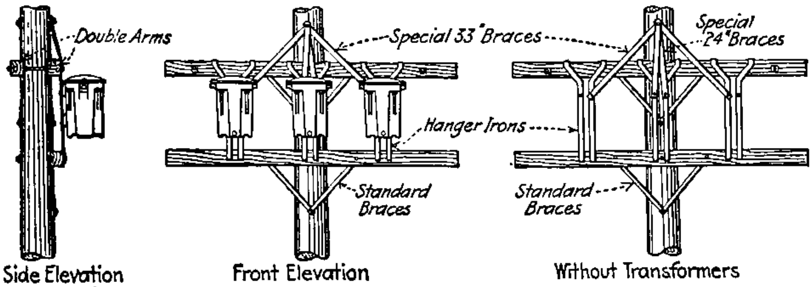


FIG. 54.—Method of supporting three 5-kva. transformers.

85. Method of Mounting Three 5-kva. Transformers. (Fig. 54.)—The construction should be similar to that outlined in the preceding paragraphs, excepting that the special braces supporting the outside transformers are 33 in. between centers of holes. It is also advisable to place an additional cross-arm on the rear side of the pole. This arm braces the front arm, and provides a place where fuse blocks can be mounted.

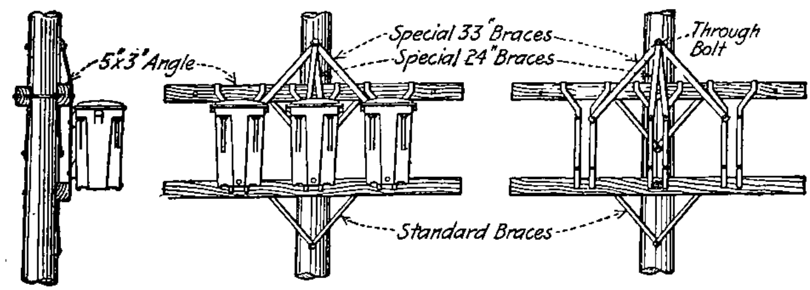


FIG. 55.—Method of supporting three 10-kva. transformers.

86. Method of Mounting Three 10-kva. Transformers. (Figs. 55 and 56.)—The construction is similar to that for three 5-kva. transformers with the following addition: The top arm supporting the transformers should be reinforced with a piece of angle iron 5×3 in. × the length of cross-arm, which should be placed with the 3-in. leg on the top of the arm.

The average life of long leaf yellow pine cross-arms has been found from observation to be from four to six years. When these arms are carrying unusually heavy loads, such as supporting heavy transformers, their useful life as such is considerably decreased. The braces are introduced so that the use of two or more cross-

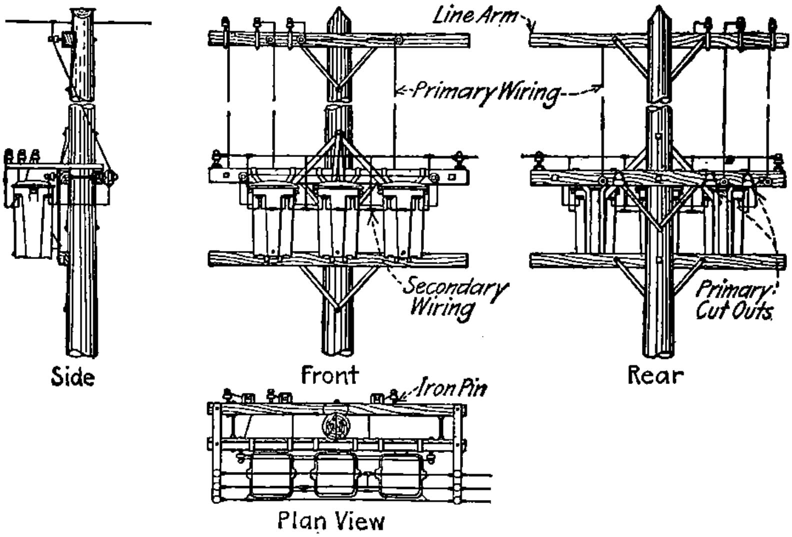


FIG. 56.—Wiring for three 5-kva. or for three 10-kva. transformers.

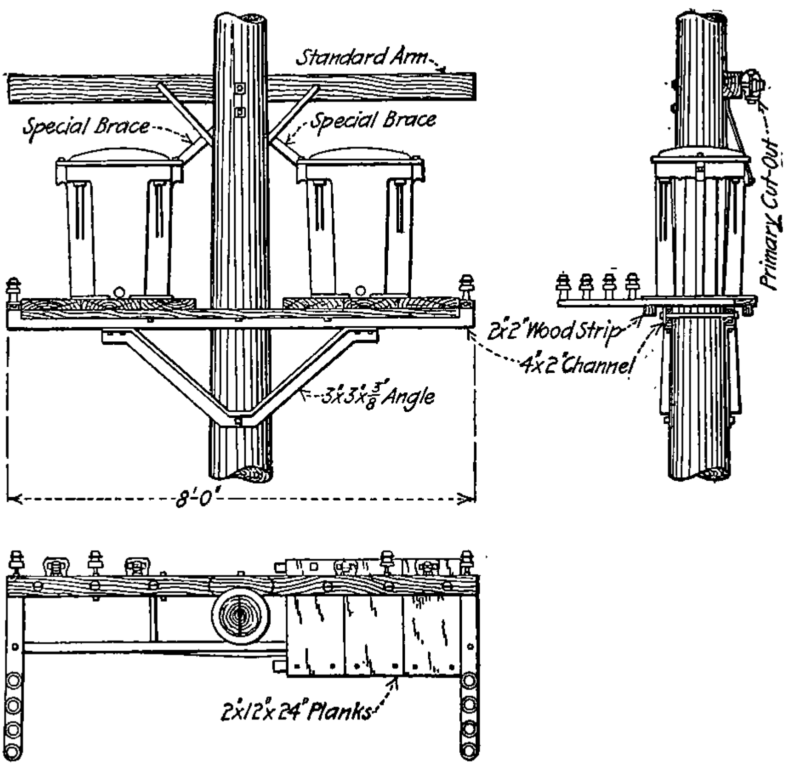


FIG. 57.—Single pole platform for two 20-kva., two 30-kva. or one 50-kva. transformer.

arms to provide equivalent mechanical strength will be unnecessary. They also insure against a transformer falling off.

87. Method of Mounting Two 20-kva., Two 30-kva. or One 50-kva. Transformer. (Fig. 57.)—For transformers of these capacities a single-pole platform is recommended. The beams for the platform should be 4 in. ×6 lb., channel iron 8 ft. long. The braces used are a single piece of angle iron 3×3×⅜ in. bent in a

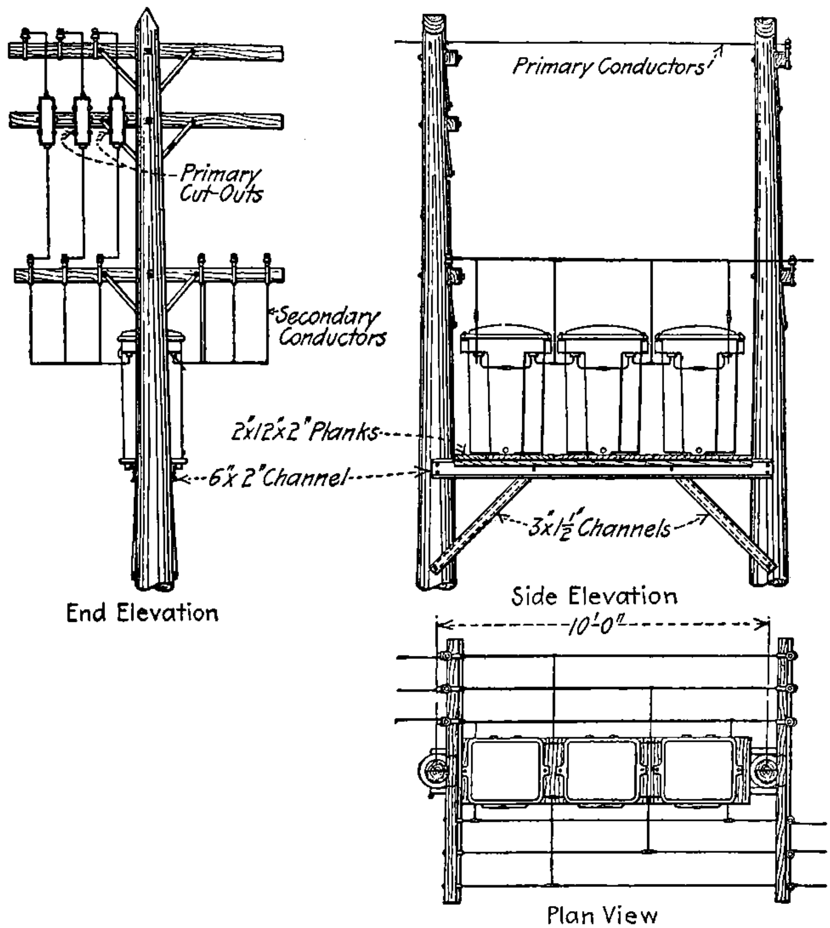


FIG. 58.—Double pole platform for three 20-kva., two 50-kva., or three 50-kva. transformers.

V shape. Pine or oak planks 2×12×24 in. are to be laid across the channel irons for the transformers to rest upon. The wooden platform is to be held together by a 2×2 in. strip of wood running on the outside of the channel iron, to which the planks are secured by 4-in. wood screws or 20-penny nails.

88. Method of Mounting Three 20-kva., Three 30-kva., Two 50-kva. or One 50-kva. Transformer. (Fig. 58.)—The poles should be spaced 10 ft. apart on centers. The main channel irons are 6 in. ×10 lb. × 10 ft. 6 in. over all. Braces are of 3 in. ×4 lb. channel.

SECTION VI

ILLUMINATION [1]

[1] The compiler acknowledges the assistance of Messrs. Chas. R. Riker and S. Sidney Neu in the preparation of this section.

1. **Physiological Features of Illumination.**—In order to understand the principles of scientific illumination, it is necessary to understand the mechanism of the eye.

Fig. 1 (From *Primer of Illumination* copyright by Illuminating Engineering Society) shows the parts of the eye as they would appear if it were cut through from back to front vertically. In the process of seeing, the light passes through the cornea, pupil, and lens of the eye to the retina, just as in a camera light passes through the lens to the sensitized film. The picture is formed on the retina, which is a layer made up of the ends of nerve fibers which gather into the optic nerve and go directly to the brain.

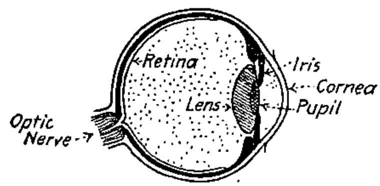


FIG. 1.—The eye—essential parts shown in section.

The optic nerve sends along the picture to the brain. The lens of the eye, unlike that of the camera, automatically changes in thickness to focus or make a clear image on the retina for seeing at different distances. This focusing action is called the accommodation of the eye, and when the light is dim or bad the focusing muscle vainly hunts for some focus which may make objects look

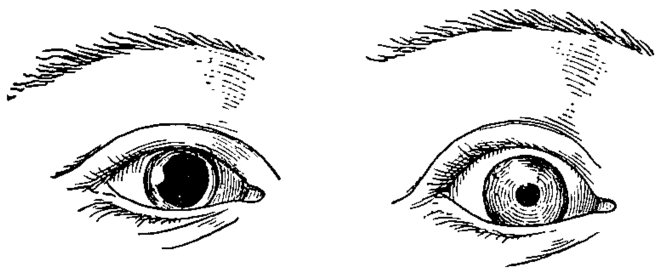


FIG. 2.—Expansion and contraction of the pupil of the eye.

clear and gets tired in trying to do it. The muscles which move the eye about also get tired in the same way and the result is eyestrain, which stirs up pain and headache just as any other over-tired muscles of the body may set up an ache.

The iris (which gives the eye its color) serves to regulate the amount of light which reaches the eye. In very dim light it opens out making the pupil big, as shown in Fig. 2, and in very bright

light it shuts up as shown, and thus keeps out a flood of brilliant light which might hurt the retina. The protective action of the pupil is pretty good, but by no means complete, for it seldom gets smaller than shown in the illustration, however bright the light. From a study of Fig. 2 we may deduce:

(a) When trying to see any object, do not allow a light to shine into the eyes, nor face a brightly lighted area. In addition to tiring the retina, the superfluous light causes the pupil to contract, so that less light from the illuminated object reaches the retina. An object which would seem well lighted in a room with dark walls, and no light shining in the eyes, will appear poorly lighted in a bright room with light walls, or when a light is shining in the eyes, simply because the pupil is smaller. This also explains why a higher light intensity is necessary in the day time than at night. It is generally easier to read with the same light source in a room having dark walls than if the walls are light in color—though the total illumination on the page will probably be less. Reflected light from glossy paper produces the same effect as light surroundings. The effect produced by a light shining directly into the eyes is termed *glare.*

(b) A fluctuating light causes the pupil to be constantly changing. This is very tiring to the muscles which control the iris, and if long continued may even work a permanent injury.

(c) The lens of the eye is not corrected, as is a photographic lens, for color variations. It cannot focus sharply red and blue light from the same object simultaneously, although this is ordinarily not noticed. As white light is composed of all colors, it follows that we can see more clearly, *i.e.*, objects appear sharper and more distinct, by a monochromatic light (light of only one color) than by even daylight. The light from the mercury vapor lamps closely approximates this condition.

(d) Illumination should be uniform; otherwise the eye, in continually attempting to adapt itself to the unequal conditions, becomes tired in the same way as with a fluctuating light.

Correct illumination enables one to see clearly with minimum tiring of the eyes. To secure this, all the above conditions must be satisfied.

2. **A line of vision** is a line drawn from a given point to an assumed natural position of the eye of an observer. When a lamp is concealed from the eye of an observer by a reflector the lamp is out of the line of vision of the observer, but if the observer changes his position until he can see the lamp then it is in his line of vision.

3. **Visual Acuity.**—Experiments have shown that if the intensity of illumination is gradually increased the following facts are noticeable: *First*, that a certain definite intensity of illumination is required before the object can be distinguished; *second*, that as the intensity of illumination is increased, the visual acuity is increased in proportion, that is, the object becomes more easily seen, up to a certain intensity of illumination; *third*, that beyond a certain point, increasing the intensity of illumination does not result in a proportional increase in visual acuity. This is shown graphically in Fig. 3. It is therefore apparent that more than a certain amount

of illumination, depending on conditions and purpose, is wasteful, in that it does not make things any more clearly seen.

4. **Effect of Daylight on Illumination.**—Daylight is so much more intense than artificial illumination that it makes artificial lighting appear dim by contrast. Experiments show that when some daylight is present, from 50 to 100 per cent. greater intensity of illumination is required. This is because the eye gets used to the high intensity of illumination on all objects by daylight, and there are no deep shadows to relieve the monotony.

5. **The intensities of natural illumination** (Bell, *Standard Handbook*) vary very greatly, ranging up or down according to relation of the point considered to windows and sunlight. The intensity of the diffuse illumination near a south window may rise to 20 ft-c. or more; with less brilliant exposure it may be 10, or 5 or 3 ft-c., and so on down as one passes to less favorable positions and gets down to fractions of a foot-candle. The illumination, for example, where this paragraph is being written near a west window on a rainy day is about 3 ft-c., while 10 ft. further within the room it has fallen to less than 0.5 ft-c. by which it is difficult to read coarse print. So far as ordinary work goes any illumination above say 2 ft-c. is about equally good. When daylight drops materially below this, one has to resort to artificial light, and there is a strong tendency to use much more than is necessary to the detriment of the eyes. Under a desk lamp an illumination of 10 ft-c. is not an exceptional amount, but it is more than double that which can generally be advantageously utilized by the eye.

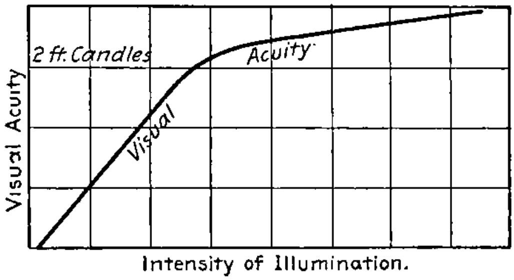


FIG. 3.—Characteristic curve of visual acuity.

6. **Direct lighting** is that wherein the light source is visible and the light is distributed directly from it.

7. **Indirect lighting** is that form wherein the light source is entirely hidden. The light is projected to the ceiling and walls from which it is reflected downward.

7a. **Indirect Compared with Direct Lighting** (H. W. Shalling).—Obtaining a large portion of the illumination indirectly has the following disadvantages as compared with direct lighting.

(1) Lower efficiency; to produce a given illumination requires about twice as much light with indirect lighting as with efficient direct lighting.

(2) More rapid depreciation due to the collection of dirt.

(3) A lower degree of perspective, since sharp shadows are largely eliminated.

(4) An unduly bright ceiling which often gives an unpleasant psychological effect, especially when the opaque unit of the indirect lighting forms a contrast with the brightly lighted ceiling.

8. The three fundamental quantities upon which the art of illumination is based are:

1. *Intensity*, or luminous intensity, which defines the light-giving power of a source and which is measured in candle-power.

2. *Illumination*, or light-flux density, which is measured in foot-candles.

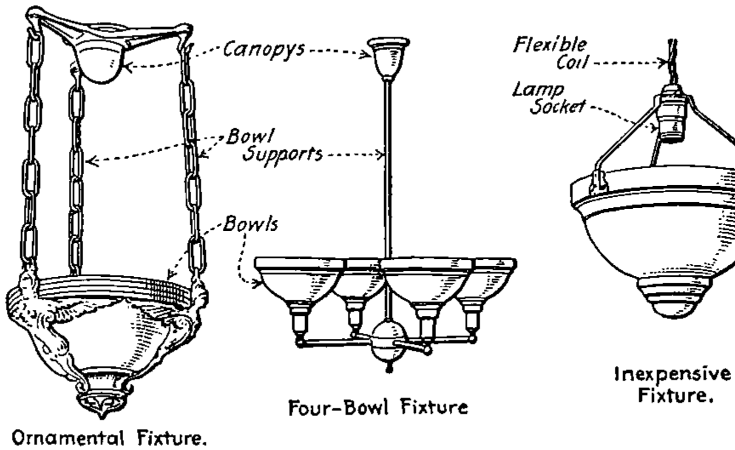


Fig. 4.—Examples of fixtures for indirect lighting.

3. *Intrinsic brilliancy*, which is measured by the luminous intensity per unit of area and in candle-power per square inch.

9. Candle-power.—The light-giving power of a luminous source is expressed in candle-power. It is determined by comparing the lamp either with a standard maintained by the National Bureau of Standards at Washington, D.C., or with a well-seasoned lamp that has been accurately measured to this standard and thus serves as a secondary standard. A light source generally gives more light in one direction than it does in another. (See Fig. 5.) Thus a direct-current arc lamp gives more light at an angle 45 degrees below the horizontal than in any other direction. The candle-power of a lamp therefore means nothing unless the direction is also specified. The candle-power generally is different in different directions.

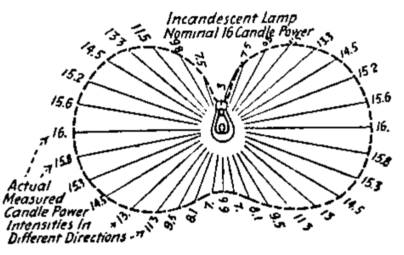


Fig. 5.—Actual candle-power intensities in different directions from a 16-c.p. carbon-filament incandescent lamp.

10. Mean Horizontal Candle-power.—The average of the candle-powers of a lamp in all directions in a horizontal plane is called the mean horizontal candle-power. Incandescent lamps were formerly rated by their mean horizontal candle-power. Two lamps rated the same (mean horizontal) candle-power may thus differ widely in their light-giving powers above and below the horizontal.

11. Mean Lower Hemispherical Candle-power.—The average of the candle-power of a lamp in all directions in the lower hemisphere is called the mean lower hemispherical candle-power of the lamp. As applied to incandescent lamps, the lamp is assumed to have the bulb down, base up. This term is of little importance where lamps are to be used with reflectors.

12. Mean Spherical Candle-power.—The average of the candle-power of a lamp in all directions is called the mean spherical candle-power. This term is of most importance as it is an index to the total light-giving power of the lamp in all directions.

13. Foot-candles—Candle-feet—Lux.—The unit of intensity of illumination is the foot-candle or candle-foot. It can be defined in two ways, both of which mean the same: 1 ft-c. is

(1) The intensity of illumination produced by a 1 c-p. source at a distance of 1 ft.

(2) The intensity of illumination produced by one lumen when spread over 1 sq. ft. of surface. The illumination on the interior surface of the sphere of Fig. 6 is 1 ft-c.

The lux is a unit of intensity of illumination employed when using the metric system. It is the intensity of illumination produced by a 1 c-p. source at a distance of 1 m., or that produced by one lumen when spread over 1 sq. m., 1 lux = .0929 ft-c., 1 ft-c. = 10.76 lux.

13A. The efficiency of an electric light source is ordinarily given in *watts per candle*, which means watts per mean horizontal candle-power. However, this method is unsatisfactory in that candle-power is not a true measure of the total light produced by the lamp. Furthermore, as the efficiency, on the above basis, increases, the figure expressing it decreases. A better method of expressing efficiency is in *lumens per watt.*

14. The reduction factor of a light source is the ratio of the mean spherical candle-power to the mean horizontal candle-power. Few sources radiate uniformly in all directions, and since most incandescent lamps have their maximum intensity in the horizontal direction, it is seen that the reduction factor must usually be less than one. According to this definition, the mean spherical candle-power can be obtained by multiplying the mean horizontal candle-power by the reduction factor.

15. Factors for Obtaining Mean Spherical Candle-power

Type of incandescent-lamp light source	Reduction factor
Carbon, oval anchored filament	0.825
Gem 50 watt, 20 c-p. filament	0.825
Gem 100, 125, 187, 250 watt filament	0.820
Tantalum filament	0.790
Tungsten (*Mazda*), multiple, vacuum, 105–125 volts	0.780
Tungsten (*Mazda*), multiple, vacuum, 220–250 volts	0.790
Tungsten (*Mazda C*), multiple, gas filled, nitrogen, 105–125 volts	0.800
Tungsten (*Mazda C*), series, gas filled, for ordinary circuits, 60, 80, 100 c-p.	0.760
Tungsten (*Mazda C*), series, gas filled, for ordinary circuits, 250, 400, 600 c-p.	0.800
Tungsten (*Mazda C*), series, gas filled, 20-amp. circuits, 600 and 1000 c-p.	0.780

16. Economical Intensities of Illumination in Foot-candles

(National Electric Lamp Association)

Application	Foot-candles
Armory or drill hall	3.0
Art Gallery	
White statuary	2.5
Bronze statuary	7.0
Paintings	5.0
Assembly Room	3.5
Auditorium	2.0
Automobile showroom	5.0
Automobile (interior)	1.0
Ball room	3.0
Bank	3.0
Bar room	3.0
Barber shop	2.5
Blacksmith shop	3.0
Billboard	8.0
Billiard room (general)	0.8
Billiard table	5.0
Bowling alley—	
Alley	1.5
Pins	4.0
Cafe (see saloon)	2.5
Carpenter shop	4.0
Court room	2.5
Church	2.0
Club—	
See Hotel, Residence, etc.	
Dance hall	2.0
Depot waiting room	1.5
Desk	4.0
Draughting room	8.0
Engraving	10.0
Factory—	
General illumination only, where additional special illumination of each machine or bench is provided	1.5
Local bench illumination	4.0
Complete (no local) illumination	4.0
Fire Stations—	
When an alarm is turned in	3.0
At other times	1.0
Foundry	3.0
Garage	2.0
Gymnasium	2.5
Hospital—	
Corridors	0.5
Wards (with no local illumination supplied)	1.5
Wards (with local illumination supplied)	0.5
Operating-table	12.5
Hotels—	
Corridor	0.6
Bed room	1.5
Lobby	2.0
Dining room	2.0
Writing room	2.0
Laundry	2.0
Library—	
Stock room	1.5
Reading room (with no local illumination supplied)	3.5
Reading room (with local illumination supplied)	0.7
Machine shop—	
Rough work	6.0
Average work	2.0
Fine work	4.0
Market	3.0
Moving-picture theater	1.5
Museum	3.0
Office (no local lights)	4.0
Pattern shops	4.0
Power house	3.0
Postal service	7.0
Public square	0.8
Reading (ordinary print)	2.0
Reading (fine print)	2.5
Residence—	
Porch	0.2
Hall (entrance)	0.7
Reception room	1.5
Sitting room	1.5
Library	2.0
Dining room	1.5
Kitchen	2.0
Laundry	1.5
Hall (upstairs)	0.5
Bed room	1.5
Bath room	2.0
Cellar	0.6
Store room	0.7
Rug rack	15.0
School—	
Class room	2.5
Assembly room	2.0
Cloak room	0.8
Corridor	0.8
Manual training	3.0
Drawing	5.0
Sewing (light goods)	4.0
(dark goods)	8.0
Shipping room	2.0
Show window[1]—	
Light goods	7.0
Medium goods	15.0
Dark goods	20.0
Sign	8.0
Stable	1.0
Station (railroad)	2.0
Stenographer	5.0
Stereotyping	4.0
Stock room	1.5
Store—	
Art	4.0
Baker	3.0

[1] Depends largely on character of street and other features of location.

17. Economical Intensities of Illumination—(*Continued*)

Application	Foot-candles	Application	Foot-candles
Store—		Store—	
Book	3.5	Piano	4.0
Butcher	3.5	Shoe	3.5
China	2.5	Stationery	3.5
Cigar	3.0	Tailor	4.0
Clothing	5.0	Tobacco	3.0
Cloak and suit	5.0	Street—	
Confectionery	3.0	Business (not including light from show windows and signs)	0.5
Decorator	3.0	Residence	0.1
Drug	4.0	Prominent residence districts	0.2
Dry goods	4.0	Country roads	0.05
Florist	3.0	Studio	4.0
Furniture	4.5	Swimming pool	2.0
Furrier	5.0	Telephone exchange (general)	3.0
Grocery	3.0	Theater—	
Hardware	4.5	Lobby	3.0
Hat	4.0	Auditorium	2.0
Jewelry	4.5	Train sheds	1.0
Lace	3.0	Typesetting	8.0
Leather	3.5	Warehouse	1.5
Meat	3.5	Wharf	1.0
Men's furnishings	3.5		
Millinery	4.0		
Music	3.5		
Notions	3.0		

18. Economical Intensities.—The above intensities of illumination are recommended for various purposes. These intensities enable objects to be seen with all the clearness generally necessary in the places mentioned. Thus, in draughting rooms greater intensity is required than in swimming-pool buildings, because more detail must be brought out. On billboards greater intensity is required than in a library reading room to enable the signs to be read at a great distance.

19. Average Intrinsic Brilliancy of Various Illuminants

Light source	Candle-power per sq. in.	Light source	Candle-power per sq. in.
Moore tube	0.3–1.75	Incandescent lamps:	
Opal-shaded incandescent lamp	0.5–3.0	Tantalum, 2.0 watts per candle	700–800
Frosted electric incandescent lamp	2–8	Tungsten, 1.25 watts per candle	850–1000
Candle	3–4	Tungsten, 1.0 watts per candle	950–1050
Gas flame	3–8	Nernst, 1.5 watts per candle	2200
Oil lamp	3–8	Sun, on horizon	2000
Cooper-Hewitt lamp	10–20	Flaming arc lamp	5000
Welsbach gas mantle	20–50	Calcium light	5000
Acetylene burner	60–100	Open arc lamp	10,000 50,000
Enclosed a-c. arc lamp	75–200	Open arc crater	200,000
Enclosed d-c. arc lamp	100–500	Sun, 30 degrees above horizon	500,000
Incandescent lamps:		Sun, at zenith	600,000
Carbon, 3.5 watts per candle	350–400		
Carbon, 3.1 watts per candle	450–500		
Gem, 2.5 watts per candle	625		

20. Intrinsic Brilliancy.—Lights of greater intrinsic brilliancy than 4 to 6 c-p. per sq. in. produce glare; that is, they tire the muscles and retina of the eye and prevent it from seeing objects clearly. It is well to avoid placing sources of light of greater intrinsic brilliancy than 1 c-p. per sq. in. in the field of vision. Intrinsic brilliancy is total candle-power per unit area of the source of light. Brilliant light sources in the line of vision should be protected by frosted or translucent shades.

21. Flux of Light. Lumen.—For purposes of calculation it is convenient to consider the light given out by any source as a flow, stream or flux from the source outward. The flux generated by a point source of 1 c-p. in a unit solid angle is called one lumen. In Fig. 6, if we assume the square to measure 1 in. on each side and to lie on the surface of a sphere 1 in. in radius, the light of 1 c-p. at the center would generate one lumen in the solid angle enclosed by the lines *abcd*. As the total surface of this sphere is 4π times $1 = 4 \times 3.1416 \times 1 = 12.56$ sq. in., the total flux emitted by a point source of 1 c-p. is 12.56 lumens. A source of 2 mean spherical c-p. would emit $2 \times 12.56 = 25.12$ lumens, and so on.

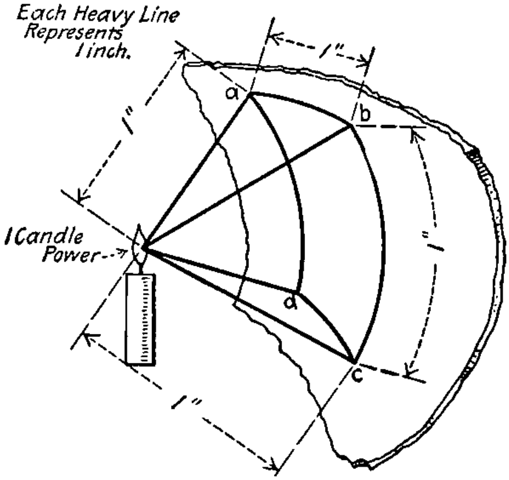


FIG. 6.—Flux of light in unit solid angle.

22. Intensity of Normal Illumination.—The inverse square law can probably be best understood by referring to Figs. 7 and 8. Consider first Fig. 7, in which the light from a light source is directed by a theoretically perfect parabolic reflector. A reflector of this type has, when the light source is properly placed within it, the property of projecting all of the light in perfectly parallel rays or in a beam. With a theoretically perfect reflector and with the light projected through an absolutely transparent medium the quantity of light at any point in the beam, as for instance at A, Fig. 7, would be the same as at any other point in the beam, as B (Fig. 7). Hence the intensity of illumination, or the brightness of the light, would be the same on A as on B. Parabolic reflectors that are used for automobile head lights give a result that approximates this condition. Obviously a perfect parabolic reflector and a perfectly transparent medium are impossible. The brightness of the beam of light projected by an automobile lamp diminishes as the distance from the lamp increases due to the imperfectness of the reflector, to the dirt and smoke in the air and to the reflection and absorption caused by the particles in suspension in the air.

This property of a parabolic reflector is noted merely to show that light is a perfectly tangible thing just as water is and that the amount or volume of light produced by a source is a perfectly definite quantity. The beam of light, projected from a source in a perfect parabolic reflector, through a perfectly transparent medium would extend out an infinite distance and the intensity of light at any point in the beam would be the same.

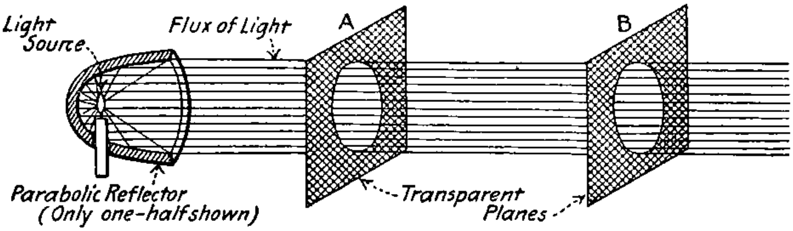


FIG. 7.—Light projected by a parabolic reflector.

Now consider the natural tendency of light (undirected by a reflector) which is to radiate from its source in all directions. It spreads out as it were. Therefore the greater the distance of any point from such a source the lower will be the intensity or brightness at that point. Consider Fig. 8. If the light from source L falls normally or at right angles on a surface A at a distance LA from the source it will illuminate A to a certain intensity or brightness. If instead it falls on a surface B, distant LB (LB being twice LA)

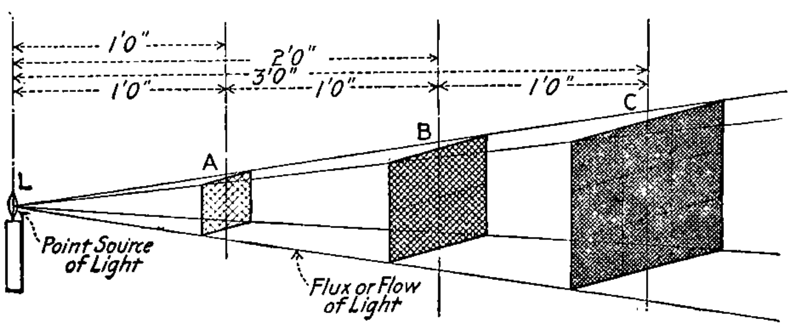


FIG. 8.—The radiation of light.

the same total number of lumens or quantity of light will illuminate a surface twice as wide and twice as high or of four times the area. As the same quantity of light is thus spread out over four times the area the average illumination on B will be but $\frac{1}{4}$ of that on A. If the same quantity of light from the same source falls on surface C (distant LC from L) the flux or beam of light will be spread out over a surface nine times the area of A and the average illumination will be but $\frac{1}{9}$ that on A.

In every case where light is radiated from a point-source to some point the intensity of illumination at the point is inversely propor-

tional to the square of the distance of the point from the source. This law can be expressed as a formula thus:

$$I = \frac{cp}{D^2} \text{ or } D = \sqrt{\frac{cp}{I}} \text{ or } cp = ID^2$$

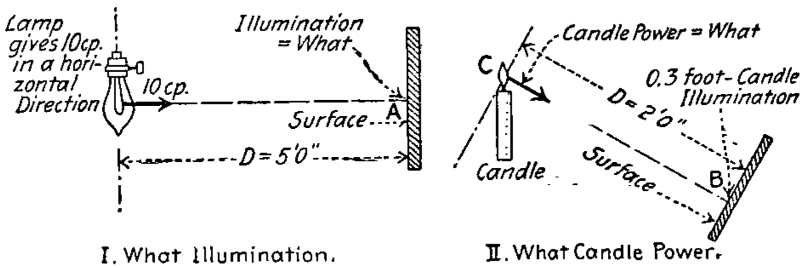


FIG. 9.—Illustrating the inverse square law.

wherein $I=$ the intensity of illumination in foot-candles on a surface normal (at right angles) to the direction of the light rays; cp = candle-power of the light source in the given direction and D is the distance from the source to the surface in feet.

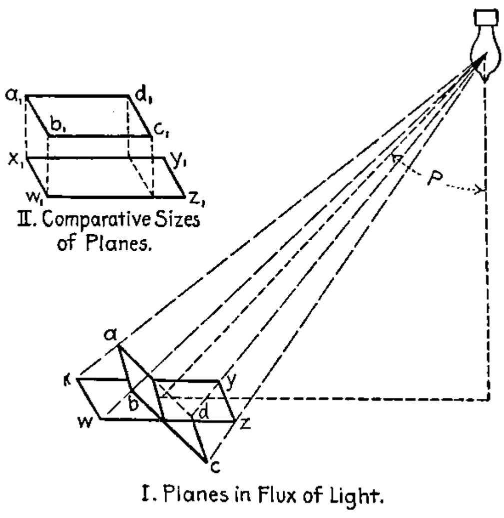


FIG. 10.—Illustrating the theory of the cosine law.

Example.—In Fig. 9, *I*, what is the intensity of illumination at the point *A* on the surface? The lamp produces an intensity of 10 c-p. in a horizontal direction and the surface is 5 ft. from the lamp.

Solution.—Substitute the values in the formula:

$$I = \frac{cp}{D^2} = \frac{10}{5 \times 5} = \frac{10}{25} = 0.4 \text{ ft-c.}$$

Therefore there is an illumination at the point *A* of 0.4 ft-c.

Example.—In Fig. 9, *II*, the illumination at point *B* is 0.3 ft-c. and the surface is 2 ft. from the light source, what is the candle-power of the light source in the direction *CB*?

Solution.—Substitute the values in the formula:

$$cp = ID^2 = 0.3 \times 2 \times 2 = 1.2 \text{ c-p.}$$

Therefore the candle produces 1.2 c-p in the direction *CB*.

23. Limitations of the Inverse Square Law.—Although the inverse square law applies with absolute accuracy only to light emitted from a source so small that it may be considered as a mere point, in practice results are sufficiently accurate if the distance from the source to the point at which the light is measured is ten to fifteen times as great as the apparent size of the light source.

24. Intensity of Illumination on Horizontal Surfaces. The Cosine Law.—(See Fig. 10.) The inverse square law and formula

(Par. 22) indicate how the intensity of illumination, on a surface normal or at right angles to the rays from the source of light, may be computed. Such a surface is indicated by *abcd*, Fig. 10, *I*. The intensity at the center of this surface (*abcd*) would be computed with the formula of **22.**

$$I = \frac{cp}{D^2}$$

Now consider the surface *wxyz* which lies in a horizontal plane but which is inclined in relation to the direction of the light from the source. However, the same quantity of light or the same number of lumens (the beam of light included within the pyramid is formed by the dashed lines) illuminates *abcd* as illuminates *wxyz*. *Wxyz* is actually larger than *abcd* as shown at *II*. Since the same

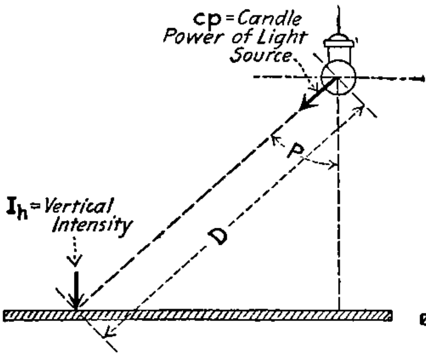


FIG. 11.—Notation for the first cosine law formula.

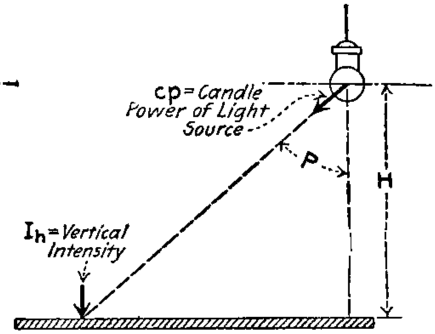


FIG. 12.—Notation for the second cosine law formula.

quantity of light illuminates a larger area in one case than in the other it is evident that the average intensity on the larger area must be less than the smaller one. The reduction in intensity on the area *wxyz* below that of *abcd* is obtained by multiplying the intensity of *abcd* by a factor, the cosine of angle *P*. A table of cosines is given in the first section of this book.

Expressing this statement as a formula using the notation of Fig. 11.

$$I_h = \frac{cp}{D^2} \times \cos P \quad \text{or} \quad D = \sqrt{\frac{cp \times \cos P}{I_h}} \quad \text{or} \quad cp = \frac{I_h \times D^2}{\cos P}$$

wherein I_h = vertical intensity in foot-candles of the illumination on the horizontal surface; cp = the candle-power of the light source in the given direction, D = distance in feet from the point under consideration to the light source and $\cos P$ = the cosine of the angle P as taken from a table of cosines. (Such a table, condensed, is given in the first section of this book.)

The above formula can be converted into this more convenient form (Fig. 12).

$$I_h = \frac{cp}{H^2} \times (\cos P)^3$$

Wherein the letters all have the same meanings as above except that H = the vertical height in feet of the light source above the horizontal surface illuminated.

25. The value for candle-power (cp) for use in the above formulas should not be taken as the nominal rated candle-power of the light source but should be taken from a photometric curve or from manufacturers' data as the candle-power in the particular direction under considerations as illustrated in following examples.

Example.—A lamp is located 12 ft. above a table (Fig. 13, *I*) and in such a position that the angle P is 60 degrees. Assume the candle-power of the lamp is 40 in this direction (30 degrees below the horizontal). What is the vertical intensity at the table or in other words what is the intensity of illumination on the table?

Solution.—From the table of cosines in the first section of this book it will be found that cosine (or cos) of 60 degrees = 0.5. Substitute the values from Fig. 13, *I*, in the formula:

$$Ih = \frac{cp}{H^2} \times (\cos P)^3 = \frac{40}{12 \times 12} \times 0.5 \times 0.5 \times 0.5 = \frac{40 \times 0.125}{144} = 0.035 \text{ ft-c.}$$

Therefore the vertical illumination at point Ih is 0.035 ft-c.

Example.—What would be the illumination on a book held at right angles to the beam of light as in Fig. 13, *II*? The distance from the book to the light source would be 24 ft.

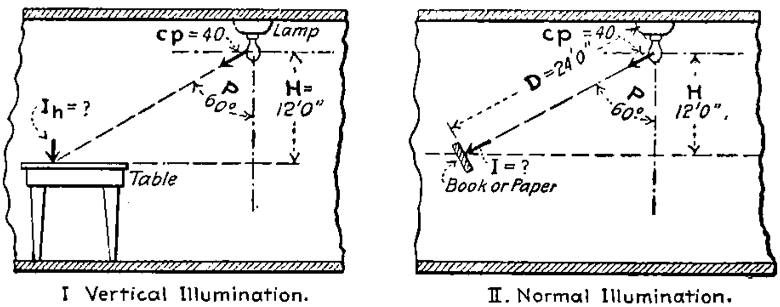


FIG. 13.—Example of computing vertical illumination.

Solution.—Substitute in the formula of 24:

$$I = \frac{cp}{D^2} = \frac{40}{24 \times 24} = \frac{40}{576} = 0.070 \text{ ft-c.}$$

Therefore the illumination at the point I on a book held at right angles to the beam of light would be 0.070 ft-c.

26. The calculation for intensity of illumination on a vertical surface is quite similar to that for a horizontal surface. (See 24.) The formula is (see Fig. 14):

$$Iv = \frac{cp}{D^2} \times \sin P \text{ or } \frac{cp}{S^2} \times (\sin P)^3$$

Wherein Iv = the intensity of illumination in foot-candles on the vertical surface; cp = the candle-power of the light source in the given direction; S = horizontal distance in feet from the lamp to the surface and P = angle between the direction of light and the vertical.

27. Caution Regarding the Use of the Preceding Formulas.—It must be understood that illumination intensities derived with the above formulas give the intensity of illumination due to direct

light from the light unit, and in practice this derived value is always increased a certain amount by diffusely reflected light. This increase may be relatively large if the ceiling, walls and other objects in the room are light in color and have a high coefficient of reflection, but it is almost negligible in industrial plants, for instance, where the walls may be of dark brick, the roof and girder construction very dark in color, with the space filled with machinery of various sorts.

28. A photometric curve consists of lines, plotted on a polar diagram, which show graphically the distribution of the light about a light source and the candle-power intensities at various directions about the lamp or lamp and reflector. See Fig. 5 and other following illustrations for examples.

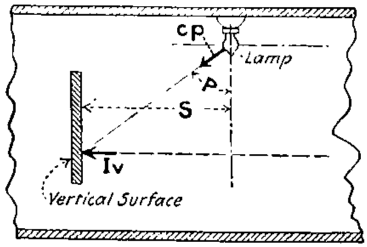
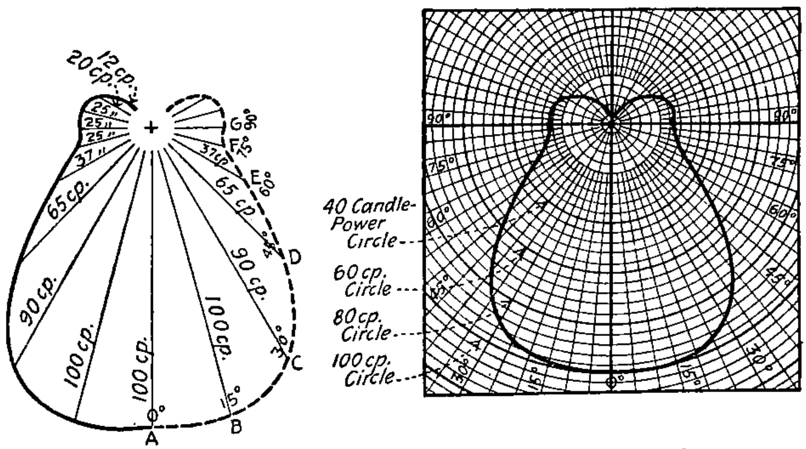


FIG. 14.—Notation for "Illumination on vertical surface" formula.

29. How to Read a Photometric Curve.—In the photometric curve of Fig. 15, *I*, the luminous intensity directly downward is indicated by measuring off this intensity on the vertical to a given scale. Thus, *XA* represents the candle-power intensity directly below the light. Similarly distances *XB*, *XC*, *XD*, *XE*, *XF*, and *XG* represent candle-power intensities given off all around



I. Elementary Curve.

II. Practical Working Curve.

FIG. 15.—Photometric curves.

the light at angles above the vertical of 15 degrees, 30 degrees, 45 degrees, 60 degress, 75 degrees, and 90 degrees. Similarly the candle-power intensities above 90 degrees can be measured off to the given scale along their respective angles. These points are then joined by a continuous line, *G*, *F*, *E*, *D*, etc., and this line, completed for the 360 degrees, is called the photometric distribution curve of the light.

Fig. 15, *I*, shows such a completed photometric curve, but in practice it is customary to use circular lines, as indicated on Fig. 15, *II*, to show the scale to which the candle-powers are plotted.

The candle-power intensity of the light-unit can be measured along as few or as many angles as necessary, the accuracy of the resultant curve being largely determined by the number of angles taken.

REFLECTORS

30. **Reflection of light** is the redirecting of light rays by a reflecting surface. Whenever light energy strikes an opaque object or surface part is absorbed by the surface and part is reflected. Light colored surfaces reflect a larger part of the light thrown on them than do dark colored surfaces, whereas dark surfaces absorb a larger part of the light, black surfaces absorb nearly all the light which reaches them. Consider first a smooth surface *AB*, Fig. 16, on which a ray of light *L* falls. This ray will be so reflected in the direction *R*, that the angle *a* is exactly equal to the angle *b*. Consider now the effect of a number of rays falling on a smooth surface *CD*, Fig. 17. Each ray will be reflected in such a way that it leaves the surface at the same angle at which it strikes it. The eye if held as shown would perceive only the light reflected into it.

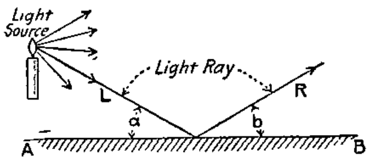


FIG. 16.—Reflection of light from a smooth surface.

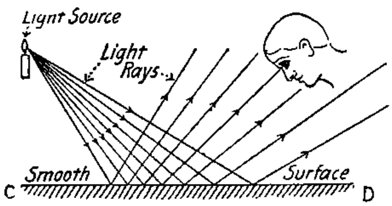


FIG. 17.—Reflection of light from a smooth surface.

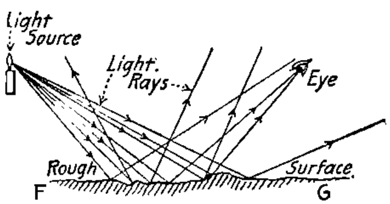


FIG. 18.—Reflection of light from a broken surface.

Consider now a broken surface such as *FG*, Fig. 18. Each ray of light is reflected from that portion of the surface on which it falls just as though that point were on a smooth surface. The result is that the light is scattered, and if the surface is irregular enough, the eye placed at any point will receive reflections from many points of the surface. All opaque surfaces except polished surfaces have innumerable minute irregularities like the surface in Fig. 18. This fact alone enables them to be seen.

31. **Reflecting Power of Surfaces.**—Different surfaces reflect different percentages of the light falling upon them. The illumination of a small room having poorly reflecting walls can often be improved by changing the wall coverings, particularly if bare lamps are used. If the room is large or if reflectors are used to throw the light downward so that not much light reaches the walls to be

reflected, a change in the wall covering will have little effect on the general illumination.

32. The following table of reflection coefficients (*Art of Illumination, Bell*) is useful in showing the relative reflective value of wall coverings in rooms.

Material	Per cent. reflection	Material	Per cent. reflection
Highly polished silver....	92	Chrome yellow paper....	62
Optical mirrors silvered on surface	70 to 85	Yellow wall paper.......	40
		Light pink paper........	36
Highly polished brass...	70 to 75	Blue wall paper.........	25
Highly polished copper...	60 to 70	Dark brown paper	13
Highly polished steel.....	60	Vermilion paper.........	12
Speculum metal.........	60 to 80	Blue green paper........	12
Polished gold...........	50 to 55	Cobalt blue.............	12
Burnished copper........	40 to 50	Glossy black paper......	5
White blotting paper.....	82	Deep chocolate paper....	4
White cartridge paper....	80	Black cloth.............	1.2
Ordinary foolscap.......	70	Black velvet............	0.4

33. Absorption is the loss of intensity or of volume of light that occurs when it passes through a reflecting or a translucent material, or when it is reflected by a reflecting surface.

34. Absorption of Light by Globes and Reflectors.—If globes are used on lamps, account must be taken of the light absorbed by the globes in calculating the total candle-power or lumens required. Table 35 gives average values (*Electrical Equipment of the Home—N. E. L. A.*).

35. Coefficients (per cent.) of Absorption of Globes and Shades

Material	Per cent. absorption	Material	Per cent. absorption
Clear glass globes.......	5 to 12	Opaline glass globes.....	15 to 40
Light sand blasted globes	10 to 20	Ground glass globes.....	20 to 30
Alabaster globes........	10 to 20	Medium opalescent globes	25 to 40
Canary-colored globes....	15 to 20		
Light blue alabaster globes.	15 to 25	Heavy opalescent globes	30 to 60
		Flame glass globes......	30 to 60
Heavy blue alabaster globes	15 to 30	Signal green globes.....	80 to 90
		Ruby glass globes......	85 to 90
Ribbed glass globes.....	15 to 30	Cobalt blue globes......	90 to 95

36. Refraction is the changing from the straight line, which a light ray normally assumes, that occurs when the ray passes from one medium into another of different density.

37. An unshaded incandescent lamp should never be tolerated under any circumstances, unless the bulb is completely frosted, and even then only in such locations as store rooms, etc., where it is desirable to light the entire wall surface, and where the eyes are normally directed away from the location of the lamps. This is because the lamp filament has a high intrinsic brilliancy; hence looking at it continually with the unprotected eye is apt to permanently injure the eye.

38. Distribution Curves of Reflectors.—The effect of a reflector in changing the direction of light given out by a light source is best expressed in the form of a distribution curve. Fig. 19 shows such a curve for a bare lamp and for the same lamp with a reflector. The curve represents the light in a single vertical plane through the center of the light unit, and it is assumed that the light in all similar vertical planes is similarly distributed. See 29 "How to read a photometric curve."

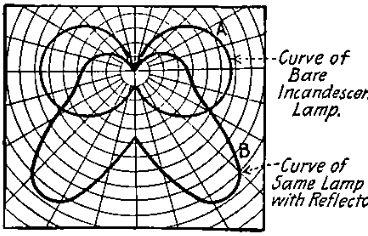


FIG. 19.—Comparison between distribution curve of a bare incandescent lamp with that of the same lamp equipped with a suitable reflector.

39. The area of the distribution curve is not proportional to the amount of light given off. Curve *B*, Fig. 19, represents a smaller total flux, by an amount equal to the absorption in the reflector, than does curve *A*, though it has a larger area. Such a curve as *B* is useful only for determining the intensity of light at any given angle below the horizontal.

40. Extensive, Intensive and Concentrating Reflectors (Fig. 20).—The Holophane Company first classified their reflectors into extensive, intensive and concentrating types, to which was later added the focussing type, the name designating the broadness

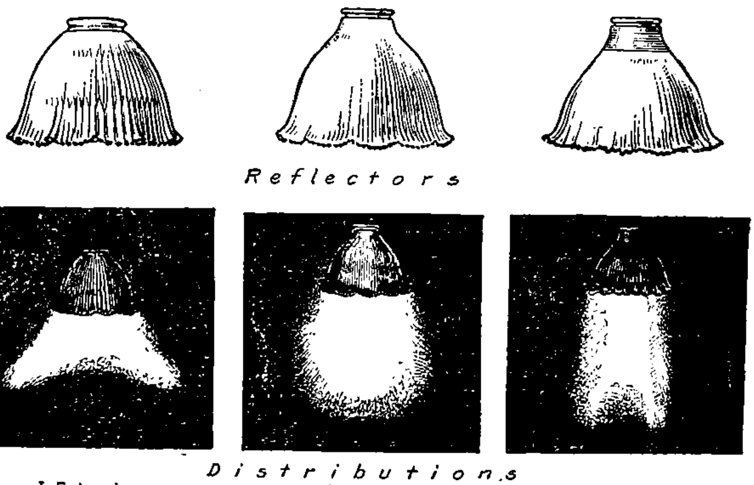


FIG. 20.—Typical prismatic glass reflectors.

of distribution as indicated by the distribution curve. These type names have since been adopted by other reflector manufacturers who make reflectors having definite and in general somewhat similar distribution curves, adapted for different mounting heights and spacing distances.

41. Application of Extensive, Intensive, Focussing and Concentrating Reflectors.—In general, focussing reflectors should be used when the distance between lamps is $\frac{3}{4}$ the mounting height; intensive reflectors should be used where the distance between lamps is about $1\frac{1}{2}$ times the mounting height; extensive reflectors should be used where the distance between lamps is twice the mounting height. These figures are averages and may not apply to all makes of reflectors. If the best results as to uniformity of illumination are desired, lamps should be suspended from ceilings at such a distance as to give proper ratio of lamp spacing to mounting height, as advised by the reflector manufacturer or as determined by plotting illumination curves.

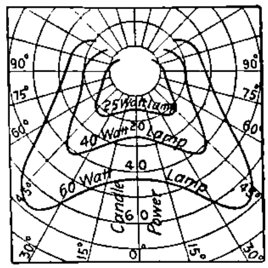


Fig. 21.—Typical photometric curves of lamps with "extensive" reflectors.

The different types (extensive, intensive, etc.) of Holophane reflector are not, in general, designed to give different illumination results. They are designed to give the same result, each type being suitable for a different condition of height and spacing of lamps.

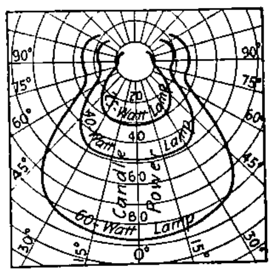


Fig. 22.—Typical photometric curves of lamps with "intensive" reflectors.

42. Extensive globes and reflectors (Fig. 20, *I*) distribute the reflected light over a wide angle below the horizontal (see Fig. 21). They are primarily for lighting moderately small rooms (say 12 ft. square) with single units or chandeliers on which the lamps hang pendant. The "extensive" type of distribution will meet the requirements of the following classes of rooms (*National Electric Lamp Association*):

1. Rooms in residences where a single light or group of lights centrally located is employed (the distribution of several units hung vertically being approximately the same as that of a single unit).

2. Small offices, waiting rooms, alcoves, etc., where the conditions are substantially as above.

3. Wide hallways having moderate height of ceiling, stock-rooms, workrooms or other cases where even, general illumination is desired from a single line of outlets.

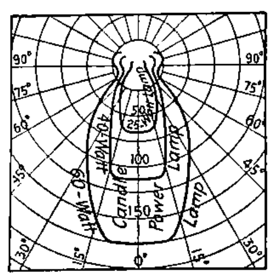


Fig. 23.—Typical photometric curves of lamps with "focussing" reflectors.

Extensive reflectors of the Holophane line give a distribution with the maximum candle-power at about 45 to 50 degrees up from the vertical.

43. Intensive globes and reflectors (Fig. 20, *II*) throw the light downward in a rather narrow angle (see Fig. 22). The primary

purpose for which the "intensive" type of distribution was designed is that of evenly illuminating large rooms by means of distributed units placed close to the ceiling in the form of squares. This system is used commonly in department and other large stores, in dining halls and restaurants, hotel and club lobbies, large offices, assembly rooms, lodge rooms, halls of moderate dimensions, council chambers, court rooms, etc., where the lights are hung high above the plane of illumination. This method of lighting is seldom used in residences.

Intensive reflectors of the Holophane type have their maximum candle-power at and below 45 degrees.

44. **Focussing globes and reflectors** (Fig. 20, *III*) concentrate the light to a small area, producing greatest intensity of illumination along the axis of the reflector (see Fig. 23). The classes of lighting for which "focussing" reflectors are designed, include the illumination of tables, desks, display windows, store counters (by means of a row of lights placed high and directly over the same) and very high rooms (where they are used in the same manner as the "intensive" type). "Focussing" reflectors give an end-on candle-power approximately $3\frac{1}{2}$ times as great as the lamp's rated horizontal candle-power. The area intensely illuminated is a circle, the diameter of which should be one-half the height of the lamp above the plane of illumination; outside this limit the intensity falls rapidly, but not so abruptly as to give the effect of a spot of light.

Holophane "focussing" reflectors give their maximum candle-powers at about 10 degrees from the vertical.

45. **Concentrating reflectors** throw the light more strongly downward than those of the focussing type, giving in some cases an end-on candle-power of eight times the rated horizontal candle-power of the bare lamp. Higher concentration can easily be obtained but is not generally required commercially.

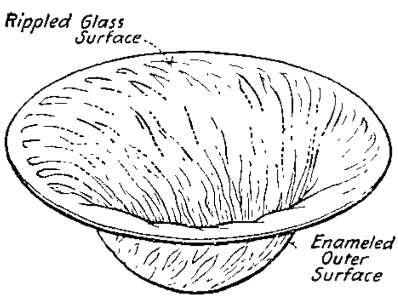


FIG. 24.—Silvered reflector for indirect lighting.

45A. **Asymmetric Reflectors** are those by which most of the light rays are thrown toward one side of the reflector. This is effected by interior vertical prisms which redirect the light from the side where it is not needed.

46. **Reflectors for Indirect Lighting.**—As manufactured by the National X-ray Reflector Company, a reflector, pointed upward, is placed under the lamp, and all of the light is directed to a light-colored ceiling. The room is illuminated by a reflected light from the ceiling. The result is a widely diffused illumination which resembles daylight; that is, shadows and general effects are similar to diffused daylight coming through a skylight or window. The decoration of the room, especially of the ceiling in which the system is to be used, should be of some light color. For best results the

ceiling should be a light cream or ivory, although somewhat darker shades give very satisfactory results. The walls of the room may be given darker tints, such as light brown, buff or tan. In all cases the lamps used with the system should be clear bulb tungsten. Each lamp has its individual reflector, especially designed, thus insuring the highest possible efficiency.

Many different types of reflectors are used, each adapted to particular conditions. One of these, a distributing type of reflector, is illustrated. Before attempting to suggest fixtures for any particular interior it is well to determine exactly what the conditions are under which the system is to be used, since the size and height of the room, color of walls and ceilings, as well as the location of the electric outlets, all affect the style of equipment that is to be specified. Styles of fixtures employed with this system are shown in Fig. 4. These fixtures are installed in exactly the same way as other electric-lighting fixtures. Some are designed for single lamps, others for multiple units, some types are made of metal, while others are constructed of "Compone" and composition. Special adaptables which may be added to the ordinary arm fixture can be procured. These adaptables hold the reflector in the correct relation to the filament of the lamp and can be readily fitted to arm fixtures that are already in place.

INCANDESCENT LAMPS

47. **Electric incandescent lamps** consist of a filament which is a highly refractory conductor mounted in a transparent glass bulb and provided with a suitable electrically connecting base. In incandescent lamps of the older types the air was, in so far as practicable, exhausted from the space within the bulb and surrounding the conductor (filament), leaving there a vacuum. But in many of the modern lamps this space is filled with an inert transparent gas—like nitrogen, for example. The conductor must have a high melting point or high vaporizing temperature and a high resistance; it must be hard and not become plastic when heated. In vacuum-type lamps the vacuum must be good, not only to prevent the oxidation of the filament, but also to prevent the loss of heat, which would reduce the efficiency. In non-vacuum-type lamps (gas-filled lamps) the gas used must be inert so as not to combine chemically with the filament material. The bulb must be transparent to permit the passage of light, not porous, so that it will retain the vacuum or inert gas, and strong to withstand handling and use.

48. **Classes or Types of Incandescent Lamps.**—There are now June, 1915) but three classes of incandescent lamps on the market, viz.: (1) *Carbon* filament, (2) *Metalized* filament or Gem, and (3) *Tungsten* filament or "Mazda." Several years ago the *tantalum* lamp was quite popular because it was then economical; this was prior to the perfection of the tungsten lamp. The demand for and manufacture of tantalum lamps has practically ceased because of the materially higher efficiency of the tungsten (or Mazda) lamp.

THE CARBON LAMP contains a filament made by carbonizing a cellulose thread, forming a filament of pure carbon. Its efficiency averages about 3.1 watts per candle. THE METALIZED FILAMENT OR GEM LAMP contains a carbon filament which has been treated in an electric furnace. This treatment imparts certain metallic properties to the carbon, thus permitting its operation at higher efficiencies than are feasible with ordinary carbon-filament lamps. Its efficiency is about 2.5 watts per candle. THE TUNGSTEN OR MAZDA LAMP has a filament of pure, drawn tungsten wire; see Art. 52.

48A. Voltage and Wattage Ratings of Incandescent Lamps.—All incandescent lamps for standard lighting circuits are now rated in watts. The watts rating of every lamp is indicated on its label. On the label is also specified the voltage at which the lamp is designed to operate. *The Three-Voltage-Rating* was formerly used, but the present practice is to show only one voltage. During the pioneer days of tungsten lamps their performances were somewhat uncertain and their first cost was high. Under these conditions the three-voltage-rating was justified inasmuch as it provided a means whereby light could be readily obtained at minimum cost with different power rates. Now, however, the lamps are low in price and their performance is uniform, hence, it appears, the three-voltage-rating is undesirable.

49. The life of an incandescent lamp (that is, the *useful* life) is always understood to mean the total hours of burning before the candle-power drops to 80 per cent. of the initial, unless the lamp becomes useless because of broken filament, or other cause prior to this. THE TOTAL OR BURNOUT LIFE of a lamp is the hours burning before failure of the filament.

50. Effect of Voltage Variation on Carbon Lamps

(All values in per cent.)

Volts	Candle-power	Watt per candle	Life
110	169	72.0	15.0
109	161	74.0	18.0
108	153	76.5	21.0
107	145	79.0	24.5
106	138	81.5	29.0
105	131	84.0	34.0
104	124	87.0	40.0
103	118	90.0	48.0
102	111	93.0	60.0
101	106	96.5	80.0
100	100	100.0	100.0
99	95	103.0	120.0
98	90	106.0	147.0
97	85	109.5	175.0
96	80	113.5	200.0
95	75	118.5	270.0
94	71	123.5	355.0
93	67	128.0	450.0
92	63	134.0	545.0
91	59	140.5	650.0
90	55	147.5	760.0

51. 220-volt vs. 110-volt Incandescent Lamps.—A number of 220–440-volt 3-wire direct-current systems have been installed with the idea of saving copper over that required for the 110–220-volt system. A comparison of lamp ratings shows that the 220-volt lamp—whether carbon, metallized or tungsten—has a much lower efficiency than the 110-volt lamp, costs more, and cannot be secured at all in the smaller sizes. Unless the load is composed so largely of motors that the lamp efficiencies and costs are over-balanced—which is not usually the case in these installations—it will be found that the saving effected by the use of 110-volt lamps will overbalance the saving in copper or the convenience effected by the higher voltage system.

52. Tungsten or Mazda Lamps.—The filament of the tungsten lamp is composed of pure metallic tungsten. When the lamps were first manufactured, the finely divided metal was mixed with a binder and squirted through a die, the binder afterward being burned away. As so made, the filaments were hairpin shape, and a number of them were connected in series in each lamp. At present the metal is drawn through dies, the same as any other wire, the final drawings being through diamond dies. The filament has a high tensile strength, is quite elastic and reasonably flexible, and the filament in each lamp is continuous, producing much better efficiency and greatly improved life. The modern lamps are capable of standing the abuse that may be accorded carbon or metallized lamps, and are very greatly superior to those originally produced, standing any reasonable amount of vibration without breakage. Unless accidentally broken, the lamps will easily average 1,000 hr. useful life. In fact, the efficiency ratings have been increased repeatedly (*i.e.*, the watts per candle decreased) in order to keep the average lamp from exceeding the rated life too greatly. The useful life of vacuum lamps has also been greatly increased by the addition of certain elements which absolutely prevent, except in case of impaired vacuum, the blackening of the globes, which was formerly so common.

It is possible to substitute tungsten lamps for either the obsolete carbon or the metallized filament lamps to give an equivalent candle-power with a saving of at least 60 per cent. in the energy consumed, or to consume an equivalent amount of energy with an increase of at least 60 per cent. in the light produced. The saving effected by the use of tungsten lamps, especially by substituting the larger size lamps for many smaller lamps, is of great importance.

The efficiencies of modern vacuum tungsten lamps range from about 1.3 watts per candle for the 10-watt lamps up to 0.9 watt per candle for the 250-watt lamps. The average for all sizes is about 1.3 or 1.4 watts per candle.

53. Tungsten Lamp Characteristics.—The positive temperature characteristic of the metallic filament makes the tungsten lamp much less sensitive to voltage variation than the carbon or even the metallized carbon filament. The resistance of the filament is very much lower when cold than at its operating temperature. This causes it to take an abnormal current when first turned on,

causing the light intensity to increase very rapidly, producing the well-known "overshooting" of tungsten lamps. This is especially noticeable when both carbon and tungsten lamps are controlled from the same switch, the white light from the tungsten lamps appearing an appreciable interval of time before the yellower light of the carbon lamps. The changes produced by this characteristic of the tungsten lamp by changes in voltage are given in **56.**

53A. Gas-filled, Tungsten Incandescent Lamps.—Until recently it has been the practice of lamp manufacturers to exhaust the bulbs of incandescent lamps to an almost perfect vacuum. It has, however, been demonstrated that it is possible to operate tungsten wire filaments at higher temperatures in a bulb containing an inert gas. The presence of this inert gas in the bulb retards the evaporation of the filament. The convection currents—hot-gas currents—carry any particles evaporated to the upper portion of the bulb where they are deposited but where they absorb very little useful light. The filaments of these lamps are coiled and mounted in a compact manner to prevent their being cooled appreciably by the passage of the rising gas. These gas-filled tungsten lamps are referred to by some manufacturers as *Mazda C* lamps to distinguish them from the vacuum tungsten lamps which are now called *Mazda B*. The gas-filled lamps operate at considerably higher efficiencies than do the vacuum lamps but are so designed as to give the same useful life, viz., 1,000 hr. It is the usual practice to make the gas-filled lamps with pear-shaped bulbs having long glass necks. The efficiencies range from 0.80 watt per candle for the 100-watt multiple lamp to 0.45 watt per candle for the 1,000-c-p., 450-watt street series lamp.

53B. Mazda or Tungsten Lamp Illumination Data
(Multiple Lamps)

Watts	Efficiency watts per candle	Mean horizontal candle-power	Efficiency spherical candle-power per watt	Efficiency lumens per watt	Total lumens	Reduction factor per cent.
Straight-side type (vacuum), 105–125 volts						
10	1.30	7.7	0.60	7.54	75	78
15	1.15	13.0	0.68	8.52	128	78
20	1.10	18.2	0.71	8.91	178	78
25	1.05	23.8	0.74	9.34	234	78
40	1.03	38.8	0.76	9.52	381	78
60	1.00	60.0	0.78	9.80	588	78
100	0.95	105.0	0.82	10.32	1,032	78
150	0.90	167.0	0.87	10.89	1,634	78
250	0.90	278.0	0.87	10.89	2,723	78
Straight-side type (vacuum), 220–250 volts						
25	1.20	20.8	0.66	8.27	207	79
40	1.12	35.7	0.71	8.86	354	79
60	1.10	54.5	0.72	9.02	541	79
100	1.06	94.3	0.75	9.37	937	79
150	1.00	150.0	0.79	9.93	1,490	79
250	0.95	263.0	0.83	10.45	2,613	79

53B. Mazda or Tungsten Lamp Illumination Data
(Multiple Lamps).—(Continued)

Watts	Efficiency watts per candle	Mean horizontal candle-power	Efficiency spherical candle-power per watt	Efficiency lumens per watt	Total lumens	Reduction factor per cent.
Pear-shape type (gas filled), 105–125 volts						
100	0.80	125.0	1.00	12.57	1,257	80
200	0.75	267.0	1.07	13.40	2,680	80
300	0.70	429.0	1.14	14.36	4,310	80
400	0.70	571.0	1.14	14.36	5,745	80
500	0.70	714.0	1.14	14 36	7,180	80
750	0.65	1,154.0	1.23	15.47	11,600	80
1,000	0.60	1,667.0	1.33	16.76	16,760	80

54. The tantalum lamp had a filament composed of metallic tantalum. It had an efficiency of about 2 watts per candle. This lamp is not satisfactory for use on alternating current as the filament becomes beady and breaks after a short life. The demand for this lamp has practically ceased, it having been superseded by the more efficient and rugged tungsten lamp.

55. Characteristics of Metallized Filament or Gem Lamps
(All values in per cent.)

Per cent., change in	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Volts	95.0	96.0	97.0	98.0	99.0	100
Amperes	95.8	96.7	97.5	98.4	99.2	100
Watts	91.0	92.8	94.6	96.4	98.2	100
C.P.	75.1	79.6	84.4	89.4	94.8	100
W.P.C.	121.0	116.6	112.2	108.0	103.7	100
Life	265.0	217.0	176.0	147.0	120.0	100
Volts		101.0	102.0	103.0	104.0	105.0
Amperes		100.8	101.6	102.4	103.2	104.1
Watts		101.8	103.6	105.5	107.3	109.3
C.P.		105.3	110.3	114.9	120.4	126.2
W.P.C.		96.5	94.0	92.0	89.0	86.5
Life		83.0	68.0	59.0	50.0	43.0

56. Characteristics of Tungsten (Mazda) Lamps
(All values in per cent.)

Per cent., change in	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Volts	95.0	96.0	97.0	98.0	99.0	100
Amperes	97.1	97.7	98.3	98.9	99.4	100
Watts	92.4	93.9	95.5	97.1	98.5	100
C.P.	83.6	86.7	90.0	93.3	96.6	100
W.P.C.	110.3	107.9	105.7	103.7	101.8	100
Life	212.0	181.0	154.0	132.0	115.0	100
Volts		101.0	102.0	103.0	104.0	105.0
Amperes		106.6	101.1	101.7	102.2	102.8
Watts		100.6	103.2	104.6	106.1	107.5
C.P.		103.4	107.0	110.0	114.4	118.2
W.P.C.		98.1	96.3	94.5	92.8	91.1
Life		86.0	74.0	64.0	56.0	48.0

57. Bases for Incandescent Lamps (See Fig. 28).—Standard nomenclature in this respect has been changed recently. One of the important changes is the substitution of the term "Screw" for "Edison" as applied to bases. The term "Bayonet" base has been adopted in place of the term "Ediswan" base. The classifying adjectives, "Medium" and "Mogul" have been adopted in place of the words "Large" and "Street Series" which were formerly

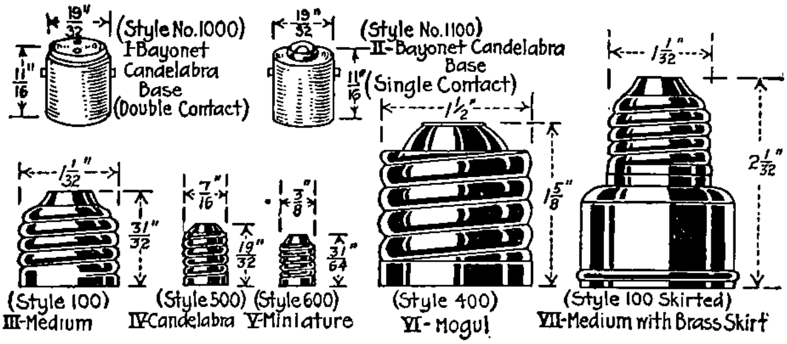


FIG. 28.—Different sizes of "screw" lamp bases.

used. Lamp bases may be divided into three general classes, as the base in a general way determines to which of the three styles the lamp belongs. 1. *Medium bases*, generally used with large lamps. 2. *Small bases*, generally used with candelabra and miniature lamps. 3. *Mogul bases*, generally used with street series lamps.

ARC LAMPS

58. Carbon Arc Lamps.—If two pieces of carbon are connected to an electric circuit and brought together, current flows through them. As the contact between the two pieces is poor, due to the nature of the materials, considerable heat is developed at that point. If the two carbons are now slowly separated, the resistance of the contact increases until the heat developed becomes sufficient to vaporize the end of one or of both of the carbons. This vapor forms a conducting path for the current after the carbons are separated and the current flows through this vapor, forming an electric "arc."

59. Open and Enclosed Electric Arc Lamps.—When the air can come freely in contact with the arc, the carbons are burned away very rapidly. This is the case with open arcs, which term includes those having a large globe into which air can enter freely. To prevent the rapid oxidation of the carbons and also to make the arc more steady, an inner globe, almost air tight, is provided on all modern carbon arc lamps. This globe and the "gas check" or cap are so designed that just enough air is admitted to burn up the carbon vapor so that it will not deposit on the globe. The increase in life of carbons that results from enclosing the arc is indicated in 60.

60. Representative Arc Lamp Data.—(*Wickenden*)

NOTE.—Values of watts per mean lower hemispherical candle-power approximate for open carbon arcs and magnetite arcs with clear globes, enclosed carbon arcs with opalescent inner globes and for flame and regenerative arcs with opal globes.

Type of lamps	Open or enclosed	Electrodes	Hours per trim	Amperes	Terminal volts	Arc volts	Terminal watts	Arc watts	Terminal power factor.	Watts per m.l.h. c-p.
D.-c series carbon arcs.	Open.....	+Upper, solid or cored. −Lower, solid.	9 to 12	9.6	50	47	480	450	....	0.6
	Open.....	+ Upper, solid or cored. − Lower, solid.	9 to 12	6.6	49.5	47	325	310	....	0.7
	Enclosed..	+ Upper, solid or cored. − Lower, solid	100 to 150	6.6	72.0	68	475	450	....	0.9
A.-c. series carbon arcs.	Enclosed..	One solid. One cored...	70 to 100	7.5	75.0	72	480	450	0.85	1.8
	Enclosed..	One solid. One cored...	70 to 100	6.6	77.0	72	425	400	0.85	2.0
D.-c. multiple carbon arcs.	Enclosed..	+ Upper, solid. − Lower, solid.	100 to 150	5.0	110.0	80	550	400	....	2.25
	Enclosed..	+ Upper, solid. − Lower, solid.	100 to 150	3.5	110.0	80	385	280	....	2.35
A.-c. multiple carbon arcs.	Enclosed..	One solid One cored...	70 to 100	6.0	110 0	72	430	375	0.65	2.40
	Enclosed..	One solid. One cored...	70 to 100	4.0	110.0	72	285	250	0.65	2.60
D.-c. flame arcs.	Open.....	Mineralized inclined....	10 to 16	8.0	55.0	45	440	360	....	0.45
	Open.....	Mineralized inclined....	10 to 16	10.0	55.0	45	550	450	....	0.40
	Open.....	Mineralized vertical....	10 to 16	8.0	55.0	38	440	304	....	0.45
	Open.....	Mineralized vertical....	10 to 16	10.0	55.0	38	550	380	....	0.40
Regenerative...	Semi-enclosed.	− Upper carbon. + Lower carbon, mineralized.	70	5.0	....	70	....	350	....	0.26
A.-c. flame arcs	Open.....	Mineralized inclined....	10 to 16	8.0	55.0	47	374	338	0.85	0.60
	Open.....	Mineralized inclined....	10 to 16	10.0	55.0	47	467	423	0.85	0.55
	Open.....	Mineralized vertical....	10 to 16	10.0	55.0	40	467	360	0.85	0.55
Magnetite......	Open.....	+ Copper. − Metallic oxide.	150 to 180	4.0	80.0	78	320	312	....	0.70
	Open.....	+ Copper. − Metallic oxide.	70 to 100	6.6	80.0	78	528	515	....	0.45

The carbons of an enclosed carbon arc lamp should burn 100 hr. on alternating current and 150 to 180 hr. on direct current if properly operated. Also as the air is excluded the carbons can be burned farther apart, resulting in better light distribution.

To secure satisfactory operation of an enclosed arc, however, care is necessary in the selection of carbons, both as to exact size and quality. Sufficient air must be admitted to unite with the carbon vapor as it is given off or it will deposit on the globe; too much air will greatly decrease the life per trim. If the diameter is not right, either too great or too small, air will be admitted through the gas check. If the quality of the carbon is poor, a deposit will form on the inner globe and discolor it.

61. **Flame Arc Lamps.**—Any of the ordinary carbon arcs can be made to flame by increasing the arc length or the current density. Such a flame gives off little or no light and hence is disadvantageous. By feeding into the arc certain metallic salts the arc flame can be made to produce light—the color varying with the metal used. Calcium—especially calcium fluoride—produces a yellow-colored light of very high efficiency. Strontium salts produce a reddish color and barium and titanium salts a brilliant white, at a somewhat reduced efficiency. The metallic salts are introduced into the flame by using either carbons cored with a mixture of soft carbon with the desired salt or salts or an electrode impregnated throughout with the desired compound. The carbons may be vertical, and co-axial as in the ordinary arc, but in most open-flame lamps they are inclined in a V-shape. There is thus no obstruction to the light below the horizontal. The arc burns in a cup-shaped economizer of a refractory material, which serves as a reflector, to shield the arc from air currents, and to prevent it from running up the carbons. A small magnet just above the economizer serves to "blow" the arc downward into a bow shape.

62. **The open-flame carbon arc** is dirty, giving off offensive fumes, and is very costly to maintain on account of the short life of the carbons, which are quite expensive. These defects have been overcome by enclosing the arc in an air-tight chamber.

63. **Candle-power of Inclined Electrode Flame Arc Lamps.**—The light from this type of lamp is given off at its greatest intensity in a direction nearly under the lamp. This is excellent for display lighting but not so satisfactory for street illumination and for this purpose the light distribution from the lamp is modified with a suitable reflector.

64. **Long-burning or Enclosed Flame-carbon Arc Lamps.**—Several manufacturers have recently placed on the market flame arc lamps constructed on the principle of the enclosed carbon lamp, *i.e.*, having an enclosed arc chamber from which free access of air is prevented. Some of these lamps have a burning life of as much as 100 hr. per trim. The globe is kept free from the deposit of soot by arranging the air circulation and condensing chambers in which the fumes deposit. These lamps preserve the advantage of the flame arc lamp—high light efficiency—and do not have most of its objectionable features.

65. The enclosed flame arc lamp, the arc of which is essentially that of the ordinary open flame arc lamps, has a burning life per trim of 100 hr. and compares favorably in candle-power and efficiency with the short-burning open-flame arc lamp. To secure long burning life of the carbons, the arc is enclosed in a chamber to which the supply of air is limited, as in the case of the standard enclosed arc lamp. In the flame-carbon lamp, however, the efficiency is reduced very little by the enclosure.

66. Magnetite, Luminous, or Metallic Flame Arc Lamps.—There are several makes of lamps on the market using one electrode of metal, that requires very infrequent renewal, and one of metallic oxides. These lamps combine the principles of the carbon arc and the flame arc, in that both the arc stream and the electrodes are highly luminous. These lamps have the peculiarity that the negative electrode burns away while the positive electrode is consumed very slowly. This limits these lamps to direct-current circuits. The negative electrode of these lamps is a very poor conductor when cold and therefore a conducting wire is generally run through its center to carry current to the arc, the electrode serving principally as a supply of substance to be burned in the arc. In one make of this lamp the negative is placed at the bottom and in another at the top.

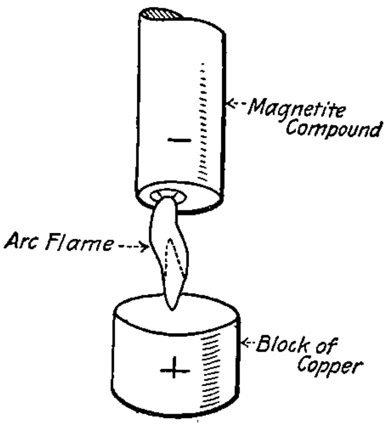


FIG. 29.—Electrodes of metallic flame lamp.

The negative electrode (Fig. 29) or cathode has a life of 160 to 200 hours. The arc flame is brightest near the negative electrode and decreases in brilliancy and volume as it nears the positive electrode. Mechanisms in these luminous lamps feed the negative electrode intermittently by restriking the arc. When the current is thrown on the feeding magnets are energized, bringing the electrodes together and striking the arc. A shunt magnet connected around the arc acts when the voltage caused by lengthening of the arc is sufficiently increased. This closes a contact which short-circuits the arc, causing the feeding magnets to strike the arc again with sufficient force to dislodge any drops of slag which may have accumulated.

The magnetite arc is well adapted for series operation with low currents. (Wickenden.) The four-ampere lamp, designed for series operation at 80 volts per lamp, has been widely used for street illumination. The 6.6-amp. lamp has a much higher efficiency and a somewhat shorter life per trim.

67. Intensified Arc Lamps.—By using special, small diameter carbons and a high-current density in these lamps, the temperature of the arc is considerably increased, and the ends of both carbons become incandescent, giving an increased light efficiency

with a shorter life. On account of the increased temperature the light is nearly white in color, closely approaching daylight in appearance. In general these lamps are quite similar to ordinary enclosed arcs, except in one type, in which two small upper carbons, arranged in V-shape, are connected in parallel, burning, however, one at a time. When adjusted for 5 amp., and 80 volts at the arc, and equipped with two 12 in. $\times \frac{1}{4}$ in. positive and one $3\frac{1}{2}$ in. $\times \frac{3}{8}$ in. negative carbon, a life of 75 hr. is secured with an efficiency of about 1 watt per candle with clear globes.

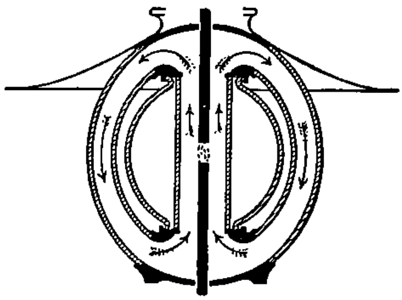


FIG. 30.—Carbon and globe arrangement in the regenerative arc lamp.

68. Regenerative Arc Lamps.—The so-called "regenerative" arc lamp (Fig. 30) is a flame arc lamp with its air currents so arranged that the fumes from the arc are returned to the arc chamber and there used over again and burned up. The arc is semi-enclosed in a glass globe, having two auxiliary glass-tubes opening into it both above and below. A circulation of the vapor is effected by the arc, the heated vapor passing around the circulating tubes from top to bottom and used in the arc many times before condensing. A specific consumption as low as 0.25 watts per mean lower hemispherical candle-power and a life per trim of 70 hr. with the advantage of a wide distribution of light is claimed.

MERCURY VAPOR LAMPS

69. The Cooper-Hewitt mercury vapor lamp consists essentially of two separate elements, the tube or light-giving part, and the operating mechanism. The tube (Fig. 31) is of clear glass of varying length, from 21 to 55 in., with electrodes at each end and containing a small quantity of metallic mercury. The air is

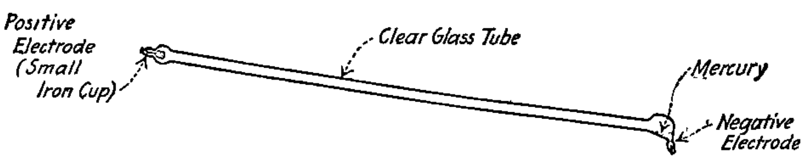


FIG. 31.—Cooper-Hewitt tubes removed from lamp.

exhausted and the tube then sealed. The mercury is held in the large bulb at one end of the tube, and serves as the negative electrode, the tube being always so suspended that this bulb is the lowest part of the tube. The positive electrode is a small iron cup at the other end of the tube. The current is conveyed to the electrodes through platinum wires sealed in the glass. The

current, passing from the positive electrode to the negative, vaporizes some of the mercury and causes the vapor to become luminous.

70. The Arc.—It being practically impossible to pass an alternating current through a mercury arc, the mercury vapor lamp is therefore essentially a direct-current lamp, and gives its best results when operating on direct current. By providing two anodes, and an auto-transformer, the lamp can be operated, however, on alternating current, using the principle of the mercury rectifier, and alternating-current lamps are regularly marketed and satisfactory in operation.

71. Quality of light from a mercury vapor lamp is peculiar. It contains no red rays, and has a peculiar bluish-green color, which greatly distorts the color values of objects viewed by it. For work in which it is not necessary to distinguish color values, two advantages are claimed by the maker. *First*, due to the absence of red rays, it is easy on the eyes, since these rays are the least effective in producing vision, and, owing to their heating power, are irritating and fatiguing to the retina. This is offset by the great preponderance of ultra-violet rays which are claimed by some to be harmful, although this has not been established experimentally. *Second*, the approximately monochromatic nature of the light promotes acuity of vision, *i.e.*, objects are seen more sharply and details are more easily discernible than by white light. The lamps are chiefly useful for drafting, photography, and for lighting large manufacturing areas.

PRINCIPLES OF ILLUMINATION DESIGN

72. General Principles of Illumination.—The general purpose of illumination is to enable things to be easily seen. As things are seen by the light reflected from them into the eye, it is necessary to have the lighting units of such number and intensity and so arranged as to make the things it is desired to see most easily seen. To do this, account must be taken of the effect of illumination on the eye. Before attempting to lay out an illumination scheme one should be familiar with the facts outlined under *Physiological Features of Illumination*, Paragraph 1.

73. Location of Lights.—No general rule can be given for location of lights for general illumination. It is always desirable to so distribute the units that uniform illumination will result. Where the number and location of lighting outlets is not determined by architectural considerations, or by the arrangement of the furniture and fixtures, it is desirable to arrange the lighting outlets in the form of squares or rectangles. It is important that the units be placed at the centers of the squares and not at the corners. Fig. 32 shows this method of locating outlets which is bad because it gives a very low intensity of illumination near the walls, as compared with that at the center of the room. Fig. 33 shows the correct way of locating outlets in the centers of the squares. In certain cases, notably in office lighting, it may be desirable to place

the outer rows of outlets somewhat nearer the side walls of the room than would be the case if symmetrically arranged as shown in the diagram, to avoid shadows.

For a given ceiling height, the smaller the squares, the less intense will be any shadows produced. The higher the ceiling, the larger the squares can be. As a general rule the side of each square should about equal the height of the ceiling. For offices that have no desk lighting the squares should be smaller, say $\frac{3}{4}$ the height of the ceiling, to reduce shadows; for stores the squares can be a little larger.

If the room is divided by partitions, each enclosure should be treated as a separate room.

Where the ceiling is divided into panels or broken up by girders, the size and location of these often determine the spacing of the lights. In such cases it is advisable to space the lighting units symmetrically according to the decorations and girders and select lamp sizes and reflectors adaptable to such spacing.

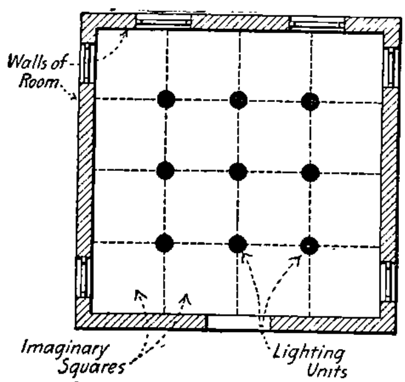


FIG. 32.—Wrong arrangement of lighting units.

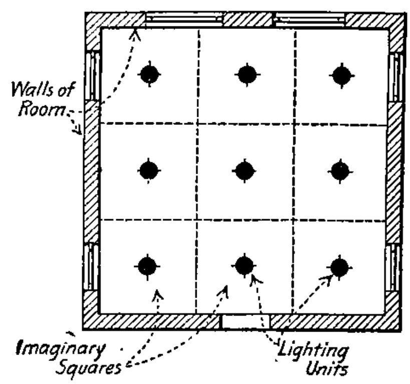


FIG. 33.—Correct arrangement of lighting units.

74. Desirable Sizes of Squares.—In lighting large offices, where individual desk lights are not employed, the squares should be comparatively small in order to have the light on any one desk coming from many units, thus merging the shadows and decreasing the glare due to regular reflections from the desk. In stores, the squares need not be so small. The size of the squares bears no relation to the intensity of illumination, but only to the evenness of illumination and depth of shadows. The following table gives the sizes of squares desirable for various spaces for direct lighting. The table cannot be strictly adhered to in all cases, and it is better not to use with the smallest ceiling height in each line the largest size square available for that height. In office lighting with no desk lights, the squares should never be made so large that extensive reflectors are necessary to obtain uniform illumination. (*Holophane Company.*)

Kind of room	Ceiling height	Desirable length of side of square
Armories	12 to 16 ft.	12 to 16 ft.
Auditoriums	12 to 16 ft.	12 to 16 ft.
Public halls	over 16 ft.	15 to 26 ft.
Rinks	over 16 ft.	15 to 26 ft.
Stores	8 to 11 ft.	8 to 11 ft.
Stores	11 to 15 ft.	10 to 16 ft.
Stores	over 15 ft.	14 to 22 ft.
Offices with individual desk lights	10 to 20 ft.	12 to 18 ft.
Offices without individual desk light	9 to 12 ft	7 to 11 ft.
Offices without individual desk light	12 to 16 ft.	9 to 14 ft.
Offices without individual desk light	over 16 ft.	11 to 18 ft.

75. A spacing chart for prismatic reflectors is shown in Fig. 34. Knowing either the spacing or mounting height, the correct reflector and its proper mounting height or spacing can be determined at a glance, or vice versa.

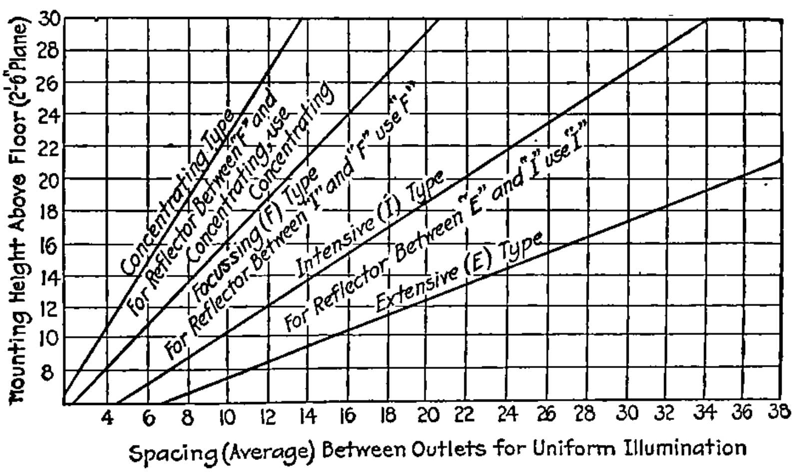


FIG. 34.—Spacing chart for reflectors. (*Holophane Company.*)

EXAMPLE.—Consider an installation for which a spacing distance of 14 ft. has been selected. With this spacing distance extensive type reflectors call for a mounting height of about $9\frac{1}{2}$ ft. above the floor. This is obviously too low to secure the best diffusion and minimum shadows, so reference is made to the diagonal in Fig. 34 representing the intensive type, and a mounting height of $13\frac{1}{2}$ ft. is found. This gives a distance from ceiling to socket of about 1 ft. with a 15-ft. ceiling.

75A. Spacing for indirect and semi-indirect lighting is determined largely by the ceiling height. The distance between units should not, in general, exceed $1\frac{2}{3}$ times the height of the ceiling above the plane to be lighted, draughting rooms and offices where close work is performed should have closer spacings.

76. Mounting height usually means the distance from the center of the lamp to the plane of illumination, but it may mean the mounting height above the floor, that is, the height from the floor to the lamp.

77. Considerations Relating to the Height and Type of Ceiling or Roof of the Area Illuminated (*Electric Journal*).—In a manu-

facturing area, the direct system is almost invariably employed and the lamps mounted within a foot or two of the ceiling or on stringer boards which span the space between the lowest members of roof trusses at intervals where rows of lamps are deemed necessary. High mounting is desirable because then the lamps are out of the way of cranes, are less liable to be broken, the glare is reduced to a minimum and in the case of a light ceiling there is more reflection and better diffusion of light. The lamps should be lowered in locations where there is horizontal overhead belting, to the level of the bottom of the belting; otherwise a portion of the light is ineffective. It may be necessary, for the same reason, to install two or three units in an area where the conditions would otherwise warrant one unit.

In office lighting the direct, indirect, or semi-indirect system may be used. With the direct system the lower intensity lamps, such as the 60-watt unit, give most satisfactory results. This is due to the fact that the glare and inconvenience from shadows is reduced to a minimum. Ordinarily the lamps should be mounted near the ceiling.

78. Approx. Desirable Mounting Heights for Tungsten Lamps

Mounting height, ft.	Size of lamp, watts	Mounting height, ft.	Size of lamp, watts
7 to 10	40		
8 to 12	50	7 to 12	60
10 to 14	80		
12 to 16	100	11 to 16	100
14 to 20	150		
17 to 27	250	16 to 28	250
25 to 35	400		
30 to 40	500	28 to 40	500

78A. Mounting Height and Spacing for Reflectors

Type of reflectors	Ratio : $\frac{\text{spacing}}{\text{height}}$ (Multiply mounting height by following to obtain spacing of lamps)	Ratio : $\frac{\text{height}}{\text{spacing}}$ (Multiply spacing by following to obtain mounting height)
Extensive..........	2.00	0.50
Intensive..........	1.25	0.80
Focussing..........	0.75	1.30
Concentrating.....	0.50	2.00

DISTRIBUTING REFLECTORS are not designed for any particular spacing. Use them for spacings wider than *extensive* where uniform or even illumination is not necessary, as in stock-rooms, warehouses and the like.

NOTE.—Where conditions call for reflectors between any two of the above types, use the more concentrating of the two. For example: If a reflector midway between an *intensive* and a *focussing* is indicated by the computations, use the *focussing* type.

79. Total Lumens given by Clear, Regular Bulb Multiple Lamps (*Correct from Incandescent Manufacturers' Data Sheets, June, 1915*).—The amount of light radiated by any electric

lamp is a perfectly definite and measurable quantity, the value of which depends upon the wattage of the lamp and the efficiency at which the lamp is burned. The unit in which quantity of light is measured is called the *lumen.*

In the following table are given the values of the total lumens radiated by each of the incandescent lamps in most common use for lighting purposes. The figures given in this table are correct for lamps operating at normal voltage with the efficiencies which are standard at this date. Use of table is explained in par. 85.

Rated watts	Mazda B or tungsten (vacuum)		Mazda C or tungsten (gas filled)		Tantalum		Gem	Carbon	
	105–125 volts	220–250 volts	105–125 volts	220–250 volts	100–130 volts	200–260 volts	100–130 volts	100–130 volts	200–275 volts
10	75	......	......	......	......	......	......	......	......
15	128	......	......	......	......	......	......	......	......
20	178	......	......	......	......	......	52	50	......
25	234	207	......	......	126	......	......	84	......
30	......	......	......	......	......	......	104	96	......
35	......	......	......	......	......	......	......	......	84
40	381	354	......	......	222	......	162	......	......
50	......	......	......	......	277	252	208	175	......
60	588	541	......	......	......	......	249	210	170
80	......	......	......	......	443	403	337	......	......
100	1,032	937	1,257	......	......	......	422	349	......
120	......	......	......	......	......	......	......	419	341
150	1,634	1,490	......	......	......	......	......	......	......
200	......	......	2,680	2,388	......	......	......	......	......
250	2,723	......	......	......	......	......	......	......	......
300	......	......	4,310	3,770	......	......	......	......	......
400	......	2,613	5,745	5,282	......	......	......	......	......
500	......	......	7,180	6,970	......	......	......	......	......
750	......	......	11,600	......	......	......	......	......	......
1,000	......	......	16,760	......	......	......	......	......	......

80. The three methods, in general use, of calculating illumination are:—(1) The Flux-Of-Light Method. (2) The Watts-Per-Square-Foot Method. (3) The Point-By-Point Method. Each has its applications and none is suitable for all problems. Only methods (1) and (2) will be discussed in this book. Method (2) is in reality a modification of method (1).

81. All of the methods of calculating illumination give approximate data. They really provide nothing more than reasonably accurate estimates which must be supplemented by the judgment of an experienced designer to afford dependable results. In laying out an illumination installation it is always a good plan to initially install in each outlet a lighting unit of a wattage somewhat larger than that the estimates indicate necessary. In case there is too much light, a lamp of smaller wattage can be used in each outlet.

82. Calculation by the "Flux of Light" Method.—The simplest method of laying out general illumination is by this method.

Knowing the intensity desired (16 and 17) on the surface to be illuminated and its area, the total flux or lumens required to produce that average illumination is readily computed:

$$lumens = \frac{Area\ (sq.\ ft.) \times Intensity\ (foot\text{-}candles)}{Constant}$$

or expressing the same thing in letters

$$F = \frac{S \times I}{c} \quad \text{and} \quad S = \frac{F \times C}{I} \quad \text{and} \quad I = \frac{F \times C}{S}$$

Wherein F = the total flux in lumens from all of the light sources that illuminate the area; S = the area illuminated in square feet; I = the average intensity in foot-candles over the entire area and C = constant from 84. Knowing the total lumens required, it is then possible to determine how many lighting units of a certain size or what size of lamps of a given number are required to provide the required flux (lumens). The lumens generated in a given lamp can be found from the table in par. 79.

83. **Illumination Constants.**—The "flux of light" method of calculation is based on the assumption that a certain proportion of the light generated in a room is thrown on the surfaces to be illuminated. Some of it is thrown on the walls and ceiling, and of this only a part is reflected to the illuminated plane. The following table indicates, approximately, the percentage of the light generated that reaches the illuminated plane under different conditions.

84. **Average Illumination Constants, Per Cent. Lumens Effective, or Efficiency of Utilization.**—If the number of total lumens produced by a light source be multiplied by the value (expressed as a decimal) for the conditions applying given below, the number of lumens effective in lighting the area will be the result. (See note.)

Ceiling	Light	Light	Medium	Light	Medium	Medium	Dark
Walls	Light	Medium	Light	Dark	Medium	Dark	Dark
[1] Prismatic, clear	60	53	......	48	48	45	40
[1] Prismatic, V.F.	53	50	......	45	45	42	38
[1] Holophane-realite	51	47	......	44	45	38	35
[1] Steel, porcelain, aluminum.	48	46	......	44	45	44	44
[1] Sudan	50	45	......	42	42	40	37
[1] Druid	48	43	......	39	38	34	31
[1] Druid, semi-indirect	40	37	......	33	25	20	......
[1] Sudan, semi-indirect	35	33	......	30	20	17	......
[1] Ivanhoe, indirect	31	28	......	25	18	15	......
Opal	50	45	44	42	42	40	37
White glass, light density.	48	44	43	40	40	36	33
Indirect and semi-indirect.	31	28	21	25	19	17	10
Bare lamps	41	35	34	30	30	25	21

NOTE that the above are average, and ordinarily safe, working constants. The actual constant to use in any case will be determined to some extent by the size of the room to be illuminated. For rooms of floor areas of less than 200 sq. ft., the constants used may be smaller than those above given by from 10 to 40 per cent. For rooms of areas larger than 1,000 sq. ft., constants greater than the above—by not more than 15 %—may be used, particularly where the walls are of medium or dark colors. [1] Holophane Works data.

85. Example, "Flux of Light" Method of Calculating Illumination.—Suppose we have a notions store to light, the dimensions of which are length, 80 ft.; width, 25 ft.; height, 12 ft. 6 in. The ceiling and walls are light. Tungsten lamps with prismatic velvet-finish reflectors are to be used.

Referring to the table in paragraph 17 we find that stores of this character should have an illumination of 3.0 ft-c. The area of the store is 80 × 25 or 2,000 sq. ft. The illumination constant for prismatic velvet-finish reflectors with tungsten lamps in rooms with light ceilings and light walls is 0.53 (paragraph 84). Substitute in the formula of 82 thus:

$$F = \frac{S \times I}{C} = \frac{2{,}000 \times 3.0}{0.53} = 11{,}300 \text{ lumens.}$$

Now determine the number and size of lamps necessary to supply this quantity of light. In 79 we find that a 25-watt tungsten lamp gives 234 lumens; a 60-watt lamp, 588 lumens; a 100-watt lamp, 1,032 lumens; and a 150-watt lamp, 1,634 lumens. (All of the data just given apply to vacuum lamps.)

The number of 25-watt lamps required would be, therefore, 11,300 ÷ 234 = 48; the number of 60-watt lamps, 11,300 ÷ 588 = 19; the number of 100-watt lamps, 11,300 ÷ 1,032 = 11; and the number of 150-watt lamps, 11,300 ÷ 1,634 = 7.

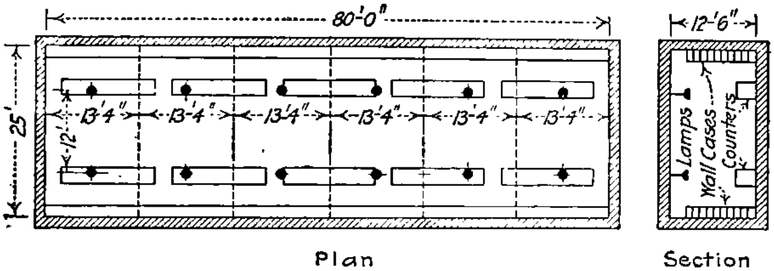


Fig. 35.—Illustrating the flux-of-light method of calculating illumination.

The lighting should be laid out in squares. (See paragraph 73.) The room would then be 2 squares wide and 6 or 7 squares long, thus requiring 12 or 14 units. Twelve 100-watt lamps would therefore about satisfy the requirements, spaced as shown in Fig. 35. It will be even better to put the lights a litt e nearer the center of the room than the walls, because of the shelving along the walls. This has been done in Fig. 35.

The reflectors should be selected as indicated in paragraph **78A.** The lamps are spaced 12 ft. to 13 ft. 4 in. apart. The ceiling height is 12½ ft., making the lamps about 10 ft. above the tops of tables and counters. The ratio of lamp spacing to height of lamps is $\frac{13}{10}$ = 1.3. By suspending the lamps at the ceiling the ratio would be $\frac{13}{10}$ = 1.25 (approx.), the correct ratio for average intensive reflectors.

86. Watts per sq. ft. Method of Designing Illumination Installations.—Where only one type of lighting unit, the tungsten lamp, for instance, is used and the mounting height of the units falls within the limits specified in 78, this method can be used. However, the *Flux of Light* is now usually considered the preferable method. The "*Watts Per Square Foot,*" of Table 87, is based on the fact that with a given type of lamp and given conditions, one foot-candle intensity will be produced on the working plane by a certain expenditure (in watts per sq. ft.) of energy.

Similar tables can be compiled for illuminants other than tungsten lamps.

In using the method, determine the size of lamp required from Table 78 and the watts per sq. ft. necessary to produce the desired intensity from Table 87. Then:

$$\frac{\textit{Wattage of lamp}}{\textit{Watts per sq. ft.}} = \textit{area of square of which lamp is the center.}$$

Taking the square root of the value representing the area of this square, the length of the side of the square, or the "ideal spacing distance" between lamps is obtained. It follows that

$$d = \sqrt{A} = \sqrt{\frac{W}{w}}$$

Wherein d = ideal spacing distance in feet; A = the area of the ideal square in square feet; W = wattage of each lamp and w = watts per square foot.

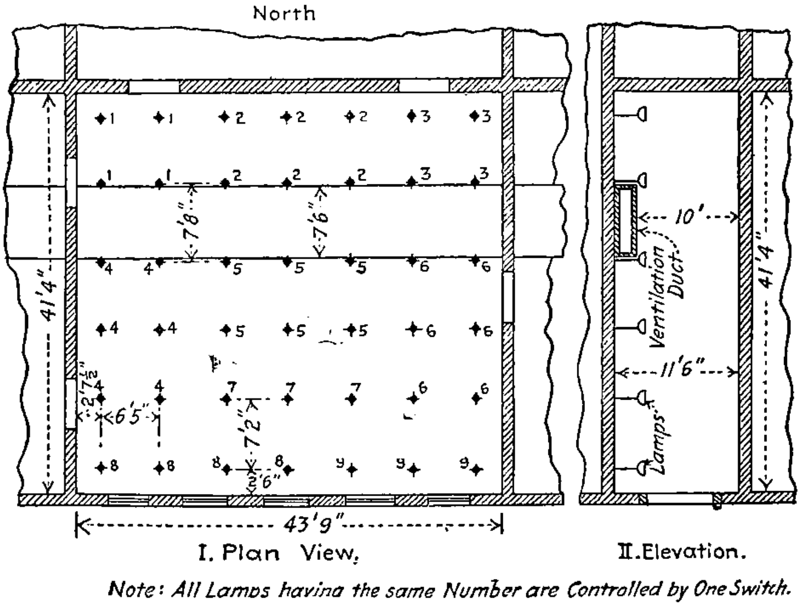


FIG. 36.—Example in laying out the illumination for an office room.

The spacing distance d having been ascertained, the designer should so lay out his area into squares or rectangles (Fig. 33) that the distance between lamps will be as nearly equal to the distance d as possible.

Where there are different ceiling heights in the same room, the size of lamp is finally decided by the relation of spacing distances to the dimensions of the room. For the sake of standardization, the number of sizes of lamps used may be reduced to four as shown in the right-hand half of Table 78.

Example of Application of the Watts per Square Foot Method.—A draughting room has a ceiling 11 ft. 6 in. high and both it and the walls are light colored. The area is 41 ft. 4 in. by 43 ft. 9 in., equalling 1,810 sq. ft. A ventilating duct causes an obstruction, as shown in Fig. 36, the bottom being 18 in. below the ceiling. An illumination of 7 ft-c. is desired. Tungsten lamps in prismatic reflectors are to be used.

The effect will be best if all the lamps are mounted with the top of the reflectors level with the bottom of the air duct. This gives a mounting height (which is always measured to the socket) of 10 ft. It is decided, upon referring to Table **78**, to use 60-watt lamps, the watts per square foot being (from Table 87) 0.19 *watts per sq. ft. per foot-candle* × 7 *ft-c.* = 1.3 *watts per sq. ft.* The ideal spacing distance, calculated out as explained, is 6 ft. 8½ in.

Laying out the lamps it is found that in a direction east to west, a spacing distance of 6 ft. 5 in. places them free from obstructions and leaves 2 ft. 7½ in. at each wall. In the other direction the width of air duct is 7 ft. 6 in., which makes 7 ft. 8 in. the minimum distance apart that the two rows of lamps can here be spaced.

Thus placing one row of lamps as near as possible to each side of the duct and laying out the rest of the system, a convenient spacing distance is found by trial to be 7 ft. 2 in., and this figure is adopted, the row of lamps nearest the walls being 2 ft. 6 in. distant therefrom. The general spacing distance is 7 ft. 2 in. by 6 ft. 5 in. = 46 sq. ft. (Fig. 36), giving $\frac{60}{46}$ = 1.3 watts per sq. ft. for each lamp and for the whole area the figure is found to be $\frac{42 \times 60}{1,810}$ = 1.4 watts per square foot.

87. Watts per Square Foot Necessary to Produce an Intensity of 1 ft-c. with Vacuum Tungsten Lamps. (*National Electric Light Association*).—Table is compiled on the assumption of an efficiency of 1 watt per candle. This is about the average efficiency for all of the commonly used sizes of vacuum tungsten lamps.

Lighting unit	Area 30 ft. × 30 ft. or larger		Small areas	
	Light ceiling		Light ceiling	
	Light walls	Dark walls	Light walls	Dark walls
Prismatic	0.19	0.21	0.27	0.30
Opal, heavy density	0.40	0.21	0.26	0.29
Opal, light density	0.24	0.27	0.34	0.37
Semi-indirect	0.29	0.35	0.43	0.53
Totally indirect	0.32	0.37	0.50	0.62

Where the efficiency of the lighting unit to be used is other than about 1 watt per candle, the watts per square foot required will vary proportionately with the efficiency. The watts required per sq. ft. varies directly as intensity in foot-candles.

88. Procedure in Designing a General Illumination Installation by the Watts per Square Foot Method (Alex. J. Airston, *Electric Journal*).—1. Measure the location, making a rough sketch of plan and elevation showing ceiling or roof trusses, positions of windows, obstacles which may affect the installation, present outlets and switching if any, and giving full dimensions.

2. Make a note of color and condition of walls, ceiling, fur-

niture, machinery and equipment as well as the class of work carried on and the closeness of application required.

3. a. Draw plans to scale.
   b. Decide on the lamp size and mounting height.
   c. Assume the watts per square foot to be used.
   d. Deduce the ideal spacing distance—$d = \sqrt{\frac{\text{Wattage of lamp}}{\text{Watts per sq. ft.}}}$
   e. Lay out positions of lamps on the plan, to give regular spacing distances, installing a row within 2 ft. 9 in. of each wall if an office, and approximating, as near as possible, to the ideal spacing distance in both directions.
   f. Make a tracing, from the plans, showing boundaries of the area and positions of lamps and old outlets, if any, also switching.
   g. Specify size of lamps and reflectors, mounting height and any other information deemed necessary for the assistance of the wiremen.
   h. Show control of lamps by numbering all lamps on one switch with the same number.

4. Check up the design at the actual location to see that each lamp is effective and free from all possible obstacles.

89. Efficiencies of Utilization for Indirect Lighting
(*National X-ray Reflector Company*)

Minimum dimension of room divided by ceiling height	Efficiency of utilization	
	Dark walls	Light walls
1.0	0.20	0.24
1.5	0.22	0.26
2.0	0.24	0.28
2.5	0.28	0.30
3.0	0.30	0.32
3.5	0.32	0.34

NOTE.—The above values are 20 per cent. low, to provide for depreciation due to dust and aging of lamps. With lamps new and reflectors clean, the efficiencies of utilization will be correspondingly higher than given in the table.

INTERIOR ILLUMINATION

90. House Lighting.—The intensity generally required in each room of a residence is given in the table of paragraph **16.** Ceiling fixtures in which the lamps hang at an angle should be avoided. As shown in Fig. 37, such fixtures tend to throw a strong light around the walls, and into the eyes of persons in the room, although the angle shown in Fig. 37 is the correct one when an incandescent lamp is completely enclosed in a ground glass or opal globe—an inefficient arrangement, but considered by some to be artistic. Lamps hanging pendant as in Fig. 38 distribute the light in useful directions. Diffusing globes or shades should be

used on all lamps which hang low enough to fall in the line of vision. Bowl-frosted lamps should be used unless the lamp itself is completely shaded.

91. **Lighting the Kitchen and the Bedroom.**—These are the two rooms in a house in which the arrangement of the lights is ordinarily most unsatisfactory. A single light or group of lights in the center of the kitchen usually compels the cook to work entirely in her own shadow, whether at the range, the sink or the kitchen cabinet or table. A couple of small bracket lights at the side of the room can usually be arranged to satisfactorily light all

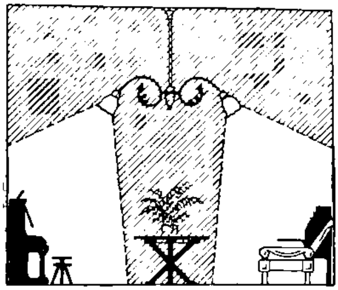


FIG. 37.—Effect of hanging residence lamps at an angle.

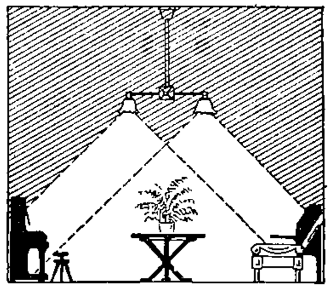


FIG. 38.—Effect of hanging residence lamps vertically.

three of these locations, and a third small light in the center of the room will give general illumination. The three need consume no more current than a single larger unit, and will give much more satisfactory service. Similarly in a bedroom, one or two bracket lights should be provided at the dressing table, with a small unit in the center of the room for general illumination. The ordinary arrangements are usually satisfactory for other rooms, except that a single ceiling or table light in a library requires that all readers shall sit with their backs toward one another to secure satisfactory reading light. This can be obviated by using scattered ceiling lights, four or more, depending on the size of the room, or by side brackets with reflectors of a type which will shade the light from the eyes of those sitting across the room.

92. **Living-rooms.**—The lighting of the living-rooms should in general be done with a view toward producing a comfortable and cheerful appearance rather than a high efficiency. The more highly efficient types of reflectors are generally out of place, as they do not allow sufficient general illumination to properly show the pictures and decorations, and therefore produce a gloomy effect.

93. **Store Lighting.**—The object of the illumination in a store is two-fold. Primarily, sufficient illumination must be provided to enable articles for sale to be seen plainly. But of almost equal importance is the advertising value. The lighting units must be so selected as to give a pleasing and cheerful appearance to the store as a whole, without glare. Stores may be divided into three classes: The small store, in which efficiency is of first importance; the large store, such as a department store, in which efficiency is neces-

sary on account of the large areas to be lighted, but must be balanced by artistic appearance, the result being a compromise between the two; and shops, large or small, in which the articles for sale are of a special type and the profits large enough that they can afford to have even the most inefficient system if it be sufficiently attractive or unique to attract customers. The general requirements which must be met are outlined in the following paragraphs:

94. General Features of Store Lighting.—The intensity of illumination must be varied with the articles which are to be sold. Furniture requires well-diffused lighting of relatively low intensity. Colored dress goods, men's clothing, rugs and carpets, etc., require

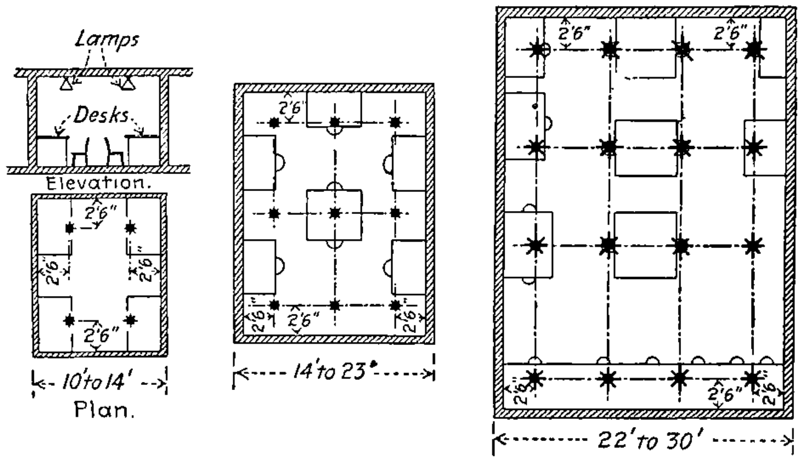


FIG. 39.—Good spacings of ceiling lights for offices (adapted from C. E. Clewell in *Electric Journal*).

a high intensity. In many installations side-light is very necessary and should be given especial attention in selecting types of units, and reflectors. Cut glass and jewelry should be so lighted as to sparkle and glitter. This requires bare lamps and mirrored reflectors. Glare is to a certain extent, in this case, unavoidable, but the light units can usually be so located as to be out of the customer's range of vision, when he is inspecting the ware. Pictures require a high intensity, with the light units at such an angle that light will not be reflected from the surface of the painting, or from the glass, directly into the observer's eyes. Individual units or mirrored trough reflectors, with linolite or tubular tungsten lamps are ordinarily used.

95. Office Lighting.—In general it is found more economical and more satisfactory to provide general rather than specific illumination in offices containing a number of desks. The lighting required can be found by the method given in a preceding paragraph. In locating the lights, the outer row should not be placed more than $2\frac{1}{2}$ ft. from the wall, to avoid shadows on desks placed about the walls. Fig. 39 shows good spacing of lamps for offices of various sizes and of ordinary height. Fig. 40 gives, in the form of a chart, spacing distances which have been found by

experience to be satisfactory with different ceiling heights. As in industrial lighting, the cost of illumination is usually so small a percentage of the salaries of the men in an office that a very small increase in their efficiency, due to less eyestrain, fewer headaches, etc., will more than pay for even an extravagant lighting system (C. E. Clewell, *Electric Journal*).

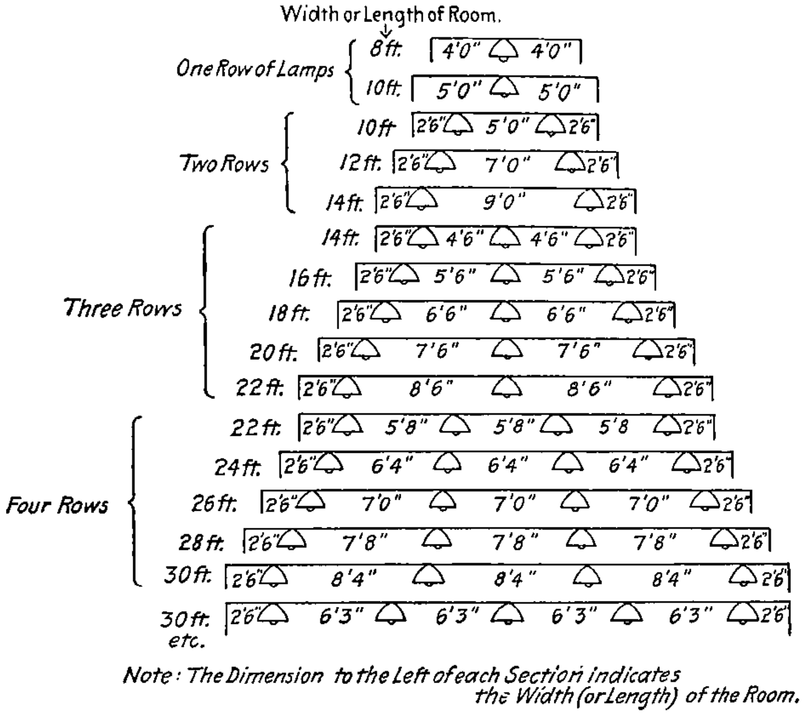


FIG. 40.—Chart showing spacing distances of lamps for offices of various sizes. (C. E. Clewell, *Electric Journal*.)

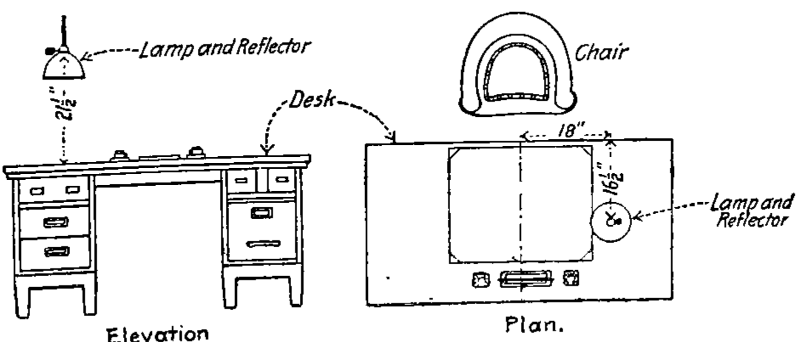


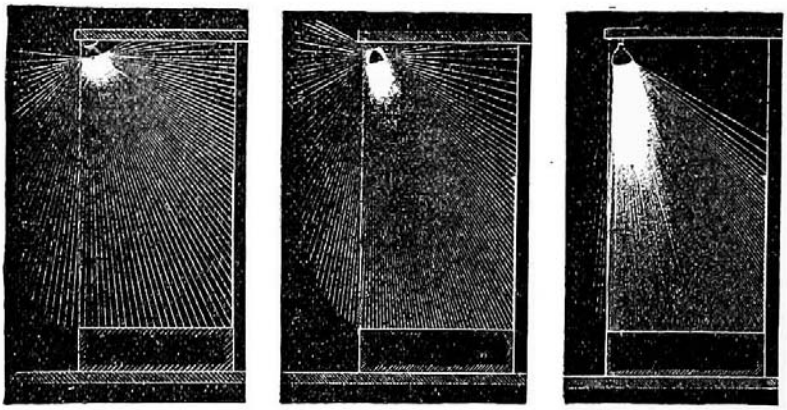
FIG. 41.—Proper method of hanging a desk lamp.

96. Specific desk lighting (Fig. 41) should as a general proposition be avoided. This is particularly true in large offices where a number of desks are located. A much better plan is to provide, as outlined under "Office Lighting," a general illumination suffi-

ciently bright to render individual desk lighting unnecessary. Specific desk lighting should generally be restricted to cases where one or two desks are located in an office chiefly used for other purposes which permit of a comparatively low degree of illumination.

Do not locate the desk light too close to the work. The light unit for a desk should be hung 21 to 24 in. above the desk, about 16 to 18 in. from the front of the desk and about 18 in. to the left of the center. The lamp should be shaded from the line of vision by a bowl type of reflector—preferably one which is opaque. Too much light is as objectionable as too little. An 8-c-p. lamp provides ample light when located as suggested. A polished reflector is intolerable as the streaks produced are very trying to the eyes.

97. Some Common-sense Facts Regarding Window Lighting (see Fig. 42) (*National X-ray Reflector Co. Catalogue*).—A good way to blind your prospective customer, so he cannot see the goods



I. II. Effect with Improperly Selected Reflectors. III. Effect with Proper Reflectors.

FIG. 42.—Illustrating good and bad window lighting.

on display in your window, is to put exposed lamps around the window borders or suspend them from chandeliers or so install them in the top of the window that his eye cannot escape them.

The light must come from in front of the goods in order to avoid shadows. If the lamps are placed in the middle of the show-window ceiling, the front of goods displayed in the front of the window will be in darkness, because of the shadows. Strange to say, many do not consider this. If the display is altogether on the bottom of the window, as in the case of a jewelry store, this shadow effect is unimportant. In the clothing or drygoods store window, it is vital.

Carrying out this principle that light must be thrown on the goods from the front of the window in order that passers-by may see no shadows on the goods, practically means that the lamps must be placed high up in the window next to the window pane, because there is no other place where they can be put to throw the light in the proper direction and keep the lamps out of the ordinary range of vision.

98. Show-window Lighting (*I. P. Frink Catalogue*).—In the average sized window, linolite lamps will give excellent results when used with properly designed reflectors on account of their high efficiency and adaptability to limited space conditions. Reflectors with standard base lamps should be used in unusually high windows, and in windows unusually deep, such as found in furniture stores, as well as in some cases where the windows in question are situated next to a store front on which there is installed a mass of exposed lamps, the glare of which makes it necessary to use an excessive amount of illumination to make the adjoining window appear properly lighted. With correctly designed reflectors there are few windows that require more light than that given by 40-watt lamps spaced 8 in. apart. With this equipment, 8 to 12 ft-c. on the floor of the windows from 8 to 12 ft. high can be developed. If the window is not boxed in, the reflector should be provided with a shield to screen the lamps from the store. If the upper part of the window back is glass, or the window is backed with mirror, the reflector should also be designed with a shield to prevent back reflection.

99. Watts and Number of Lamps Required per Front Foot for Window Lighting (National X-ray Reflector Company).—The number of lamps per front foot of window or the watts per front foot required for good window illumination, depend very much on the location of the show window, whether it is on a brilliantly lighted street and in a city where a great deal of light is commonly used in show windows, or whether it is in a town where only a limited amount of show-window lighting is common. For example, in a small country town a single reflector may give a better illumination of a window with an 8-ft. frontage than is common among the other windows in the town. In large cities where dark dry-goods and men's clothing are displayed, some merchants consider that a window cannot be too brilliantly illuminated.

On account of the efficiency of properly designed reflectors (because of the fact that they confine and direct nearly all of the light where it is wanted) it is of course not necessary to use as many lamps where the reflectors are properly designed as where they are not. Where reflectors are designed for large lamps of 105 and 60 horizontal candle-power (100 and 60 watts) respectively, the lamps can be spaced some distance apart and still give good results. Some splendidly lighted show windows in large cities have 100-watt lamps spaced 18 and 24 in. apart. In the small towns where lower standards of illumination prevail, this spacing can be safely increased to 36 in. or more.

100. In lighting counter and display cases the same rule is followed as with show-window lighting, viz: Throw the light on the goods displayed and not into the eyes of the observer. If the glare from the lamps reaches the observer's eyes he is partially blinded and the result desired is not accomplished. Tube tungsten lamps are to be preferred and they should be equipped with proper —continuous if possible—reflectors. Ordinary pear-bulb lamps can be used with suitably designed reflectors but the tube lamps give more effective results and constitute a neater installation, and

furthermore the heating of the show-case glass work is equalized, minimizing its breakage.

101. Examples of Factory Tungsten Lighting Systems

(*Factory Lighting Systems*, Clewell) (See Note Below)

These installations do not in general have drop lamps, the lamps overhead providing for nearly every requirement.

Feet and inches			[1] Size of lamp, watts	[1] Watts per sq. ft.	Class of work and character of surroundings.[2] Opal or clear prismatic glass reflectors used
Ceiling or girder height	Mounting height above floor	Spacing distance			
8–1	7–6	8–0×8–0	60	0.94	Detail work—light ceiling, no walls
9–0	8–6	8–0×8–6	100	1.47	Bench work, flat—no ceiling, dark walls
11–1	10–3	8–0×8–9	100	1.43	Bench work—no ceiling, dark walls
11–9	11–0	8–0×9–6	100	1.32	Machining—dark ceiling, no walls
11–9	11–0	8–0×8–9	100	1.43	Machine work—dark ceiling and walls
12–0	11–3	8–0×8–0	100	1.56	Machine work—dark ceiling, no walls
12–0	11–3	8–0×8–0	100	1.78	Machine work—dark ceiling, no walls
12–0	11–3	7–0×8–0	100	1.78	Bench work—dark ceiling, no walls
12–6	12–0	8–0×10–0	100	1.25	Machine work—dark ceiling, no walls
13–8	12–10	8–0×8–6	100	1.47	Machine work—dark ceiling and walls
16–0	14–6	8–0×8–9	100	1.43	Detail work—no ceiling, dark walls
16–0	15–2	8–0×10–0	100	1.25	Rough work—no ceiling, light walls
16–0	15–2	11–6×16–0	250	1.36	Painting machines—no ceiling, light walls
16–0	15–2	10–0×12–0	250	2.08	Fine die work—no ceiling, dark walls
16–0	15–2	13–0×14–0	250	1.37	Bench work—no ceiling, dark walls
24–9	21–3	10–0×12–0	250	2.08	Fine assembly work—dark ceiling, no walls
24–9	21–3	10–0×12–0	250	2.08	Machine work—dark ceiling, no walls
24–9	21–3	10–0×12–0	250	2.08	Testing—dark ceiling, no walls
25–2	21–7	10–0×12–0	250	2.08	Testing—dark ceiling, no walls

[1] These data are based on the earlier tungsten lamp efficiencies. With the present (June, 1915) efficiencies, the new 40-, 60- and 200-watt lamps would give about the same illumination respectively as the old 60-, 100- and 250-watt lamps tabulated above, and the *watts per sq. ft.* consumptions shown would therefore be decreased accordingly—an average decrease in consumption of about 30 per cent.

[2] In factory construction, manufacturing spaces often occur where the girders and columns form the boundary lines without walls. Similarly open girder construction often occurs, where no ceiling exists.

102. **The wattage required to properly illuminate display and counter cases** varies with conditions. Experience provides the only rules for this work as conditions, such as reflection from the glass work and mirrors, render calculation useless. As a general proposition, the illumination in cases should be double that in the store (J. M. Johns-Manville Co.). In an 8- to 12-ft. show-case, 100 watts (ordinary show-case reflectors and tungsten lamps) will give excellent results with an average illumination of 7 to 8 ft.-c. With mirror-lined reflectors, the same intensity may be maintained, with the same wattage, in a 12-ft. case.

EXTERIOR ILLUMINATION

103. **General Requirements for Street Lighting.**—In all four classes of street lighting (see par. 104) it is desirable to have uniform intensity, good diffusion to prevent sharp shadows, and low intrinsic brilliancy to reduce glare. It is not usually feasible to attain all of these desirable conditions. It is their high intrinsic brilliancy, particularly when clear outer globes are used, that makes the older types of arc lamps objectionable as street illuminants.

104. **Classification of Street Intensities.**—City streets are generally grouped in four classes as to illumination requirements. *Class* 1, public squares, principal business streets, streets leading to railway stations, and sections of streets where crime is prevalent, should have an illumination intensity of 0.4 to 0.6 ft.-c. *Class* 2, comprising streets where night traffic is moderate, such as business streets having little traffic at night, and the outlying parts of main thoroughfares, require about 0.2 ft.-c. *Class* 3, comprising outlying residence streets, do not require more than 0.1 to 0.15 ft.-c. *Class* 4, comprising sections of the city not built up, or country roads, are sufficiently illuminated (beacon lighting) with 0.05 ft.-c. In addition to these there may be a "white way" where 1 or even 1.5 ft.-c., in addition to the illumination produced by the window and sign lights, is permissible. (From paper by C. E. Stephens.)

105. **Electric Light Sources Available for Street Lighting.**—Arc lamps and gas-filled tungsten incandescent lamps provide the most economical illumination for streets. Of the arc lamps, the open and enclosed carbon arcs have become practically obsolete as street illuminants. The metallic flame arc has largely replaced the older forms of lamp. The color of the light is white and the distribution curve shows a maximum candle-power from 15 to 25 degrees below the horizontal. Its maintenance cost is comparatively low. The efficiency of light production varies from 0.4 to 0.5 watt per m. l. h. c-p. The light from tungsten lamps can be refracted in any desirable angle.

The flame carbon lamp is the most recent arc-lighting development. The efficiency of light production varies from 0.25 to 0.35 watt per mean lower hemispherical candle-power. The light distribution curve shows a maximum candle-power from 20 to 30 degrees below the horizontal. The maximum candle-power varies from 1,600 to 2,500 c-p., depending upon the carbons used. (C. E. Stephens.)

Tungsten series incandescent lamps are available in sizes ranging from 60 to 1,000 c-p. The efficiency of light production varies approximately from 0.8 to 0.45 watt per candle. When properly equipped with a suitable reflector, they are well suited for street illumination.

106. Number and Size of Units for Street Lighting.—Using a small number of units of very high candle-power, mounted at considerable height and placed at great distances, requires a larger total light flux to secure the minimum allowable illumination midway between units than is required with closer spacing. There is some waste of energy where the sources are spaced at great distances from one another. On the other hand, increasing the number of units increases the installation and maintenance cost of the system. In general, if energy cost is low, large units at great distances apart are better; if energy cost is high, small units placed at frequent intervals are more economical.

On streets having trees, arc lamps cannot be used because the height at which they should be mounted will cause the trees to throw dense shadows on the streets. In such cases tungsten lighting is always most suitable.

In making calculations, the point-by-point method should be used, making calculations quarter and halfway between units, under each unit, and about 25 ft. from each unit. In making these calculations it is necessary to consider only the illumination caused by the two nearest units. (C. E. Stephens.)

107. In residence street lighting the use of relatively small units is usually preferable because with the smaller units the illumination is more uniform. Another feature that should be considered in this connection is that although large units are for a given installation preferable from the standpoint of installation and maintenance costs because a minimum number of units is necessary, considerable of the light from these large units will be wasted in lighting the yards facing the street. With small units spaced closer together, most of the light falls on the street and walks and little is wasted (Fig. 43). (C. E. Stephens.)

108. Spacing and Height of Units.—The uniformity of illumination with a given unit varies with the distance between units and their height. The very nature of the street area determines that the light units must be in a single or double row along the street. The number and size of units and their height are determined by the intensity requirements and cost of operation. In making a selection of units for a given condition it is necessary, therefore, to carefully consider the curve of light distribution of the available units. Increasing the height of the lamp decreases the intensity of illumination directly under the lamp quite rapidly and does not materially change the intensity at greater distances from the lamp. The height of a lamp is usually limited on account of the extremely high cost of installation, maintenance, tree obstruction, etc. (C. E. Stephens.)

109. The actual amount of illumination to be tolerated as a minimum on the street (Bell, *Standard Handbook*) is commonly

based in the United States on getting something like the effect of average moonlight say in the neighborhood of 0.02 ft-c.

110. **Distribution of Street Illumination.**—In the illumination of a sidewalk, for example, the required minimum being 0.04 ft-c., the specification could be better fitted by common candles placed 6 ft. high and 6 ft. apart along the curb than by powerful sources of light spaced 200 ft. apart, although the latter would give more than fifty times the total light of the former. (See Fig. 43.)

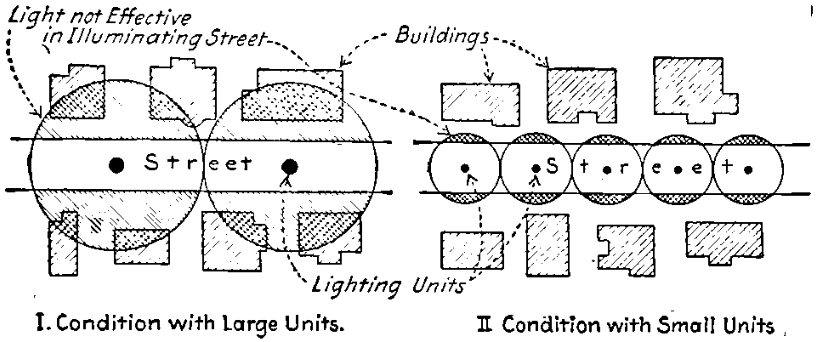


FIG. 43.—Illustrating how a considerable portion of light is ineffective in illuminating a street where high-power lighting units are used.

Some point between these extremes should evidently be chosen in the joint interest of economy and good average illumination, and a few trial computations will bring out the facts. In general, radiants of moderate power placed at moderate distances give the best illuminating effects, whether on the street or indoors.

111. **In locating arc lamps for outside illumination** one should be placed where possible at each street intersection so that the

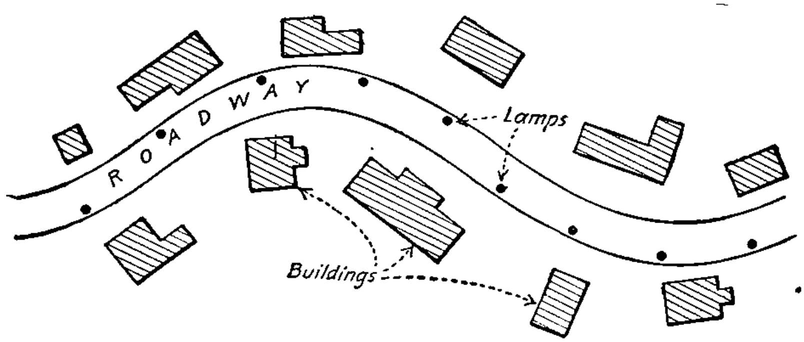


FIG. 44.—Preferable method of locating lighting units along a curved roadway.

light will be useful in all four directions. Spacing distances between street intersection lamps is a thing that must be determined by local conditions. Where blocks are long, or strong illumination is required for display purposes, one, two or even more lamps can be equidistantly located between the street intersection lamps.

112. **In locating lamps along curved roadways** it is often considered preferable to place them as suggested in Fig. 44 rather

than all on the same side of the road. When arranged as shown more lamps can be seen at one time and it is claimed that distant moving objects in the road are more effectively revealed in that they will always lie between the observer and the lights.

113. **Height of Arc Lamps for Outdoor Illumination.**—Generally speaking the lamps should be hung as high as feasible. As a rule arc lamps are hung too low for best results. From 35 to 45 ft. from the ground is probably about right for average conditions, but it is seldom feasible to place lamps this high because of practical considerations such as cost, tree shadows and the like.

114. **Comparative Example of Alternating-current Arc and Series Tungsten Street Lighting** (H. A. Hussey, *Electric Journal*). —Consider a street (Fig. 45 *I*) 50 ft. wide and 400 ft. between intersecting streets, with one alternating-current enclosed arc at each intersection. Four 60-c-p. tungsten lamps (Fig. 45 *II*) would cost less to operate per year. The tungsten lamps are mounted 12 ft. above the ground on 4-ft. brackets and are equally

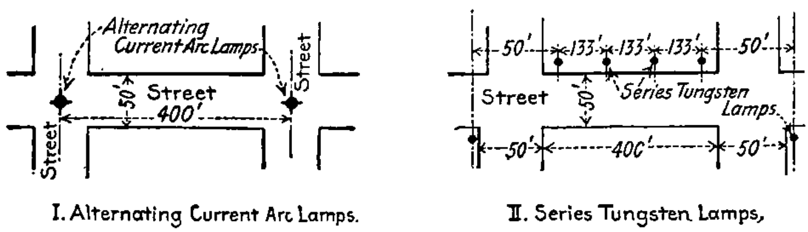


FIG. 45.—Street illuminated with enclosed arc and tungsten lamps.

spaced on one side of the street. Alternate blocks have the lamps on the opposite side of the street so that two lamps are provided at each street intersection on diagonally opposite corners, thus providing a higher illumination where most needed as well as distinctly marking street intersections. Along the center line of the street the comparative illumination on a horizontal plane at the street surface would be about as indicated in the following table. These figures show some of the advantages of series tungsten lamps. Horizontal intensity, is not the only criterion. When shadows, per cent. of light emitted reaching the working surface, uniform background, glare, etc., are considered, the advantages of the small unit become more pronounced. Unfortunately these factors cannot be stated numerically.

115. **Comparative Values, A.C. Arcs and Series Tungstens**

Quantities	Arc	[1] Tungsten
Maximum foot-candles	0.450	0.160
Minimum foot-candles	0.001	0.035
Average foot-candles	0.057	0.082
Ratio maximum to minimum	450.0	4.6
Ratio minimum tungsten to minimum arc	35	

[1] These data apply to tungsten lamps of the older and lower efficiencies.

116. **Series Tungsten Street Lighting.—The adjuster socket system** operates only on constant-potential circuits. It consists of a simple series of lamps connected across high-tension constant-potential alternating-current mains, or across the secondary terminals of a constant-potential transformer or auto-transformer. A reactance coil is connected in shunt across the terminals of each lamp. When the lamp is burning the reactance coil takes only 4 or 5 per cent. of the current. If the lamp filament is broken or the lamp removed the voltage forces the total current of the circuit through the reactance coil, magnetizing it to saturation, whereupon it produces a counter-electromotive force equal to the potential difference across the lamp when burning. This maintains the continuity of the circuit at all times.

117. **Series Tungsten Street Lighting.—In the regulator system** the series of lamps is supplied from a constant-current regulating transformer. (See Section on Transformers.) This automatically controls the current and voltage of the circuit, and maintains a constant current regardless of the number of lamps burning. A film cut-out device, consisting of a receptacle and socket located in the street hood, short-circuits the lamp and thus maintains the continuity of the circuit when a lamp burns out. The lamp cut-out, used in the regulator system for maintaining the continuity of the circuit, consists of a thin copper, aluminum or lead disc coated with an insulating enamel, placed between clips provided in the socket. If the lamp burns out, the increase of potential across the clips punctures the film between the socket clips and short-circuits the lamp.

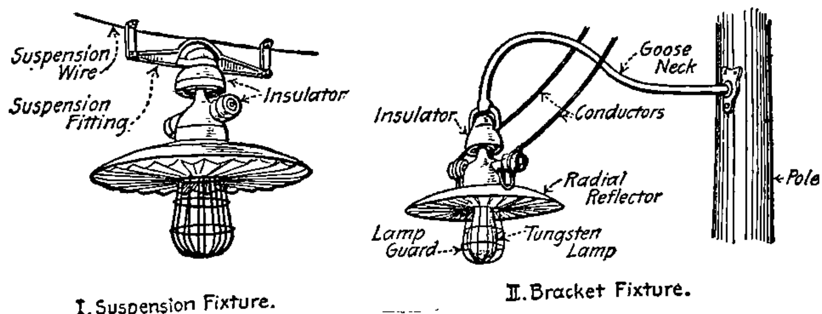


Fig. 46.—Street fixtures for tungsten lamps.

118. **Fixtures for Street Tungstens.**—Fig. 46 shows two of the most popular tungsten street-lighting fixtures. That of II is arranged for fastening to a pole, while that of I, when in service, hangs from a cable or span wire supported by two poles.

119. **In locating single light series tungsten units, along the curb** (see Fig. 46), the best results are obtained by allowing the lamps to hang from 1 to $1\frac{1}{2}$ ft. outside of the curb line. In the case of single line lighting, a distance of from 3 to 5 ft. outside of the curb line is usually desirable. Lighting units may also be placed over the center of the street, either by suspension similar to that commonly employed for arc lamps, or on ornamental standards placed on "Islands of Safety."

120. Desirable Mounting Heights for Tungsten Street Series Lamps (*National Electric Lamp Association Publication*).—In general a height of from 12 to 16 ft. is desirable for single light units ranging from 25 to 80 c-p. This height is advisable from the fact that in the majority of smaller and in some of the larger towns or cities, the streets are heavily wooded, and it is necessary to place the illuminants beneath this natural canopy of foliage. In the case of higher candle-powers as, for example, the 200-c-p. tungsten lamp, a height of 20 to 25 ft. should be maintained unless the lamp is enclosed in a diffusing globe, in which case the above-mentioned height of from 12 to 16 ft. would hold. When ornamental standards with two or more lights are used, a height slightly greater than 12 ft. but not exceeding 16 ft. may effectively be employed. The height of lamps above the street, rather than the candle-power, determines the maximum spacing of units. When lamps are placed low and at exceptionally long intervals, an object in the roadway or unevenness of the pavement is greatly exaggerated and distorted. An increase in candle-power merely deepens the shadows and increases the distortion.

121. Tungsten, Gas-Filled or Mazda C Street Series Lamps

(*STRAIGHT SIDE AND PEAR-SHAPE BULBS—July* 1, 1917)

The following lamps are for use on constant current circuits. A small compensator made for each size of lamp, is used with the 15 and 20 ampere lamps to raise the current from 5.5, 6.6 or 7.5 amperes to the 15 or 20 amperes required. The price of lamps for rectifier service which are not included in the following may be obtained on application.

Amperes	Nominal rated candle-power	Total lumens	Average volts	Type and size bulb	Diam. bulb inches	Maximum over all length, inches	*Base regularly supplied	Standard package quantity	List price, Clear	List price, Frosted
5.5	60	600	8.5	S-24½	$3\frac{1}{16}$	$7\frac{1}{4}$	Mog. screw	50	$1.00	$1.05
	80	800	10.8	S-24½	$3\frac{1}{16}$	$7\frac{1}{4}$	Mog. screw	50	1.20	1.25
	100	1000	13.0							
	250	2500	29.7	PS-35	$4\frac{3}{8}$	$9\frac{3}{4}$	Mog. screw	24	2.35	2.45
	400	4000	47.4	PS-40	5	10	Mog. screw	12	4.00	4.15
6.6	60	600	7.1	S-24½	$3\frac{1}{16}$	$7\frac{1}{4}$	Mog. screw	50	1.00	1.05
	80	800	9.1	S-24½	$3\frac{1}{16}$	$7\frac{1}{4}$	Mog. screw	50	1.20	1.25
	100	1000	10.9							
	250	2500	23.5	PS-35	$4\frac{3}{8}$	$9\frac{1}{4}$	Mog. screw	24	2.35	2.45
	400	4000	37.1	PS-40	5	10	Mog. screw	12	4.00	4.15
	600	6000	55.7	PS-40	5	10	Mog. screw	12	5.00	5.15
7.5	60	600	6.4	S-24½	$3\frac{1}{16}$	$7.\frac{1}{4}$	Mog. screw	50	1.00	1.05
	80	800	8.0	S-24½	$3\frac{1}{16}$	$7\frac{3}{4}$	Mog. screw	50	1.20	1.25
	100	1000	9.6							
	250	2500	19.6	PS-35	$4\frac{3}{8}$	$9\frac{3}{4}$	Mog. screw	24	2.35	2.45
	400	4000	30.5	PS-40	5	10	Mog. screw	12	4.00	4.15
	600	6000	45.8	PS-40	5	10	Mog. screw	12	5.00	5.15
15.0	400	4000	15.3	PS-40	5	$12\frac{1}{2}$	Mog. screw	12	4.00	4.15
20.0	600	6000	15.5	PS-40	5	$12\frac{1}{2}$	Mog: screw	12	5.00	5.15
	1000	10000	25.9	PS-40	5	$12\frac{1}{2}$	Mog. screw	12	6.00	6.15

Orders for lamps of 250 c-p. and higher should specifically state if they are to be burned in other than pendent position. **The light center length of the 15 and 20 ampere MAZDA C lamps shown above is 9½ inches for burning in pendent position and 8¼ inches where ordered for burning tip up.**

* Medium Screw Skirted Base also supplied at same price, except the 400, 600 and 1000 c-p. lamps, which are supplied only with Mogul Screw Base as indicated.

MAZDA lamps for street series service selected for use on multiple compensators or for any other purpose where a single voltage or a range of voltages closer than stated are required will take a special price which may be obtained from the manufacturer upon application.

122. When any lamp is hung so low that it lies within the range of vision of a nearby observer the glare from the unit should be eliminated by the application of a proper reflector or shade.

123. A reflector should always be used with any incandescent street-lighting lamp. Where no reflector is used a large portion of the light generated is projected above the lamp into the air and is wholly ineffective in lighting the street.

124. Where lamps are installed on streets bordered with trees the lamps should always be hung a trifle lower than the lower branches of the trees. If they are not, heavy shadows will be cast by the branches and the effectiveness of the illumination will be greatly impaired.

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Y

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